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THE PRESENT NAVAL FUEL OIL INVESTIGATION.

By LIEUTENANT JAMES E. HAMILTON, U. S. NAVY.*

In 1929 it became apparent to the Navy Department that the requirement which the Navy had maintained since the World War for Bunker "A" fuel oil was becoming increasingly difficult to meet. At that time more than half of the Navy's needs called for Bunker "A" from refineries on the East or Gulf Coasts of the United States. On the West Coast the Battle Fleet was obtaining a good grade of Bunker "B" fuel oil at Bunker "C" prices.

There actually existed, at that time, three separate problems—the supply of a satisfactory grade of fuel oil for the Navy on the East Coast, on the Gulf Coast, and on the West Coast. The Office of Naval Operations, without making any regional differentiation, directed the Bureau of Engineering to determine what grades of fuel oil, satisfactory for naval use, were readily available on the market at reasonable prices.

* Bureau of Engineering, Navy Department.

The Bureau designated a board of four officers to study the matter. The preliminary study resulted in the outline of the four following problems, quoted from a letter from the Bureau to Operations:

"(*a*) What grades of fuel oil can our ships burn with existing or projected apparatus without loss of military efficiency?

"(*b*) What grades of fuel oil can our ships bunker with existing or projected facilities without loss of military efficiency?

"(*c*) What grades and qualities of fuel oil will be available generally for naval use for the next ten years at a reasonable price or at any price?

"(*d*) What changes of installation in our ships and storage facilities will be necessary to bunker and to burn the oils found by (*c*) to be available and at what cost?"

The first two problems were undertaken first and assigned to the Scouting Fleet. The *Cincinnati* and the *Goff*, typical vessels of the cruiser and destroyer types, were selected and made extensive runs on typical viscous fuel oils on the market. Other vessels of the Scouting Fleet made additional runs and the results indicated fairly definitely that cruiser equipment would enable this type of ship to handle and burn fuel oil with a viscosity in the order of 250 seconds Saybolt Furol at 122 degrees F. For destroyers the limit was not much in excess of 100 S.S.F. at 122 degrees F.

Since practical considerations limit the Navy to one grade of fuel oil for all combatant vessels except submarines, the service tests set the upper viscosity limit for this fuel at about 100 S.S.F. at 122 degrees F. This limit must hold as long as any of the war-built destroyers remain in commission or in reserve unless these vessels are equipped with increased heating capacity for fuel oil.

One point of major importance was not covered by the *Cincinnati* and *Goff* tests. All of the fuel oils tested were straight run residua. No cracked fuel oils were tested and the statement cannot yet be made that *cracked* fuel oils with a viscosity not greater than 100 S.S.F. at 122 degrees F. can be effectively used by naval vessels.

The Bureau of Engineering Board previously mentioned was dispersed by changes of duty shortly after the conclusion of the shipboard tests. The Board's efforts to obtain an answer to ques-

tion (*c*) permitted it to draw certain general conclusions. To study this question more thoroughly, Lieutenant Commander W. H. Osgood, U.S.N., was directed to visit certain refinery districts and to study the supply of fuel oil. Osgood's report was very comprehensive and resulted in a set-up at the Naval Research Laboratory for a research study of fuel oil and its characteristics. Osgood, himself, was ordered to the Research Laboratory to supervise the work.

Osgood had outlined the problem and assembled laboratory equipment and fuel oil samples when transfer to the hospital and subsequent retirement ended his direct connection with the problem. His separation occurred just at about the time when an apparently very vicious type of cracked fuel oil was supplied to many vessels of the Battle Fleet. The principal effect of this oil was to plug fuel oil heaters very rapidly. Shortly afterward, the writer took over the supervision of the fuel oil investigation which had now become fairly urgent because of the following combination of reasons:

(*a*) The West Coast heater difficulty had, in the absence of any satisfactory test, necessitated the additional specification requirement that fuel oil should be not heavier than 0.95 in specific gravity. This requirement eliminated the particular bad fuel experienced. The gravity requirement was greatly disliked by West Coast refiners and seriously threatened the Navy's West Coast supply which, due to the redistribution of the fleet, comprised the greater part of the total.

(*b*) The Bunker "A" which had been growing scarcer on the East Coast, continued to become more so and with the withdrawal of the Navy's two to three million barrel annual need promised to disappear entirely.

(*c*) The depression cut the demand for gasoline very little but the general effect on the oil industry was to depress prices to such a point that curtailment of crude production became much easier to effect. Efforts of the industry assisted by State governments were increasingly effective in reducing the production of crude. The Federal government which was contributing moral support to the curtailment idea has since effectively entered actively under the provisions of the National Industrial Recovery Act.

(*d*) The prospect of a rising gasoline demand to be supplied from a controlled volume of crude, coupled with the possible increase of industrial activity, promised to reduce the total supply of fuel oil while at the same time the demand increased.

(*e*) It appeared that the end of the depression would mark the end of straight run residual fuel oils at least insofar as production by the large refiners was concerned.

In order to accelerate the investigation it was decided to conduct certain service tests, generally recommended by Osgood, under similated conditions ashore. The two points needing immediate answer were:

(1) Do any cracked residua make satisfactory naval fuel oil?

(2) If some do how can bad ones be discovered by test?

It was necessary to utilize facilities at the Naval Boiler Laboratory at Philadelphia, the Naval Research Laboratory at Anacostia and the Engineering Experiment Station at Annapolis. At the first, critical burning tests, at the second, chemical research, and at the latter, heating tests were begun on typical cracked residual fuel oils.

As an additional part of the investigation, a conference was held in the Bureau with representative members of the American Society for Testing Materials. The outcome of this conference was the formation of a committee with the chairmanship in the Bureau of Engineering and seven representative civilian members from the oil industry. The function of the committee was the development of a satisfactory specification for fuel oil for naval use.

At the present time the work in the three naval laboratories and in the committee is under way. Other articles in this issue describe the work which has been done to date and outline the views of the committee members and others on various phases of the problem.

THE LIMITATIONS OF THE NAVAL METHOD OF FUEL OIL PURCHASE.

By LIEUTENANT H. J. NORTON (S.C.), U. S. NAVY.*

In October, 1908, the first exclusively oil burning vessel was placed in commission by the Navy. This vessel—the U.S.S. *Cheyenne*—consumed 10,290 barrels of fuel oil during a fourteen-month period ending November, 1909, when she was placed out of commission. The Navy's fuel oil requirement afloat increased gradually. The Secretary of the Navy in his annual report for the fiscal year 1910 stated:

"All new destroyers and submarines are now designed to use fuel oil exclusively for fuel, while battleships and other large vessels are being fitted to carry oil as an auxiliary fuel."

However, in the fiscal year 1912 only about 16,000,000 gallons (381,000 barrels) were purchased. Development along the line of using liquid fuel continued and in his annual report for the fiscal year 1913, the Secretary of the Navy stated:

"Fuel oil seems fair to become the principal fuel of the Navy."

During this period the purchase of fuel oil requirements for the Navy was not much of a problem. Since that time, however, the consumption of fuel oil has gradually increased year by year until the requirements for the Fleet during the fiscal year 1933 amounted to 5,394,826 barrels of fuel oil and 88,465 barrels of Diesel oil. The period since the days of the *Cheyenne* as the only oil burner of the Navy to the present time when all combatant Naval vessels are oil burning, has brought about revolutionary developments in the Navy and in the great oil industry now producing the fuel.

Naturally, the problem of procuring this quantity of fuel oil is very different than that prevailing during 1908 and subsequent years and although Section 3728 of the Revised Statutes gives the Secretary of the Navy wide discretion in fuel purchases, it has been the practice of the Department to purchase its fuel subject

* Bureau of Supplies and Accounts, Navy Department.

to the same general principles which govern the usual Navy purchases. In this connection the limitations of the purchase of fuel for the Navy are governed by:

1. Specifications which cover fuel oil to meet the operating characteristics of Naval craft.

2. Forms of delivery required and places where delivery must be effected.

3. By price—due to specific appropriations by Congress.

4. By special and restrictive legislation. The following is quoted from the Naval Appropriation Act for the fiscal year 1934:

"Provided further, That no part of this appropriation shall be available, any provision in this Act to the contrary notwithstanding, for the purchase of any kind of fuel oil of foreign production for issue, delivery, or sale to ships at points either in the United States or its possessions where oil of the production of the United States or its possessions may be procurable, notwithstanding that oil of the production of the United States or its possessions may cost more than oil of foreign production, if such excess of cost, in the opinion of the Secretary of the Navy, which shall be conclusive, be not unreasonable."

The major principles which govern all Navy purchases are applicable to the purchase of fuel oil and these are:

(*a*) Solicitation of bids (by advertising, letters and schedules).

(*b*) Obtaining the widest possible competition.

(*c*) The award of contract to the lowest satisfactory bidder.

Specifications for fuel oil are determined primarily by the Bureau of Engineering. Due to the constantly changing methods of cracking crude oils by the various refineries, also the improvement and changes in oil burning equipment, it is vital that the question of specifications receive continuous study and that the Bureau of Engineering collaborate with the various oil producing companies and refineries. The extent to which the Bureau of Engineering is able to keep the fuel oil specifications in line with developments in the oil industry determines largely the availability of fuel oil for Naval purposes and in turn affects the price at which the fuel oil may be obtained. Obviously, it is important that fuel oil specifications conform as nearly as practicable with commercial specifications, in order that the Navy may be assured

of an ample supply of fuel. Any other policy, such as a special or uncommercial grade for Naval use, will result in a serious limitation of available supply.

For several years, the Navy has purchased grades "A," "B" and "C" fuel oil for combatant vessels. Recently, the Bureau of Engineering has promulgated a new specification covering "Navy fuel oil," based on the use of a cracked fuel, and purchases for the fiscal year 1935 will be made under this specification. It remains to be seen just to what extent this change in specification will increase or decrease the availability, and the price, of fuel oils offered to the Navy. It is believed, however, that a specification which permits a single grade of fuel oil to be used under all conditions by all vessels of the Navy is a distinct step forward and indicative of progress.

The methods of delivery also affect the procurement of fuel oil by the Navy. For this reason effort is made to specify deliveries in such forms as will obviate the need for special equipment and be similar to methods used commercially. Any deviation from commercial practice must of necessity influence prices, usually upward. For this reason conditions of delivery which may require the use of special equipment or which would delay the release of commercial equipment are avoided whenever practicable. The following forms of delivery are usually employed:

(*a*) Cargo lots into Navy tankers at contractors' docks or tanks.

(*b*) Barge lots into Navy barges at contractors' docks or tanks.

(*c*) Barge lots by contractors' barges into vessels' bunkers at anchor in the stream.

(*d*) Into ships' bunkers at contractors' docks.

Navy tankers are used to take delivery of fuel oil in cargo lots whenever possible, as this method imposes no special condition on the contractor and requires the minimum use of space at contractor's docks. It is also the most satisfactory method of delivery of fuel oil to Navy storages or direct to vessels of the Fleet.

At certain ports, particularly San Pedro, it is customary to obtain oil in Navy owned barges direct from contractor's docks and distribute same to vessels anchored in the harbor, but at other ports it has been found more satisfactory to use Navy owned

tankers for this purpose. Smaller craft are occasionally bunkered at contractor's docks, when considered advisable.

Contractor owned tankers are utilized when necessary for the transportation of fuel oil to Navy storages in the absence of Navy owned tankers. It is very seldom that this method of delivery is used, due primarily to the additional cost involved and the necessity of quick discharge, either into Navy shore storages or into Navy tankers, in order that vessels may be released and heavy demurrage charges avoided.

THE FUEL OIL MANUFACTURING PROCESS.

By K. G. MacKenzie.*

According to the A.S.T.M. tentative definition relating to petroleum, fuel oil is "Any liquid or liquefiable petroleum product burned for the generation of heat in an industrial or household furnace or firebox, or for the generation of power in a Diesel engine, exclusive of oils with a flash point below 100 degrees F., Tag closed tester, and oils burned in cotton or wool-wick burners."

The various sources of fuel oil may be classified as follows:

1. Crude oil, per se.
2. Distillates from the atmospheric distillation of crude oil.
3. Residues from the atmospheric distillation of crude oil.
4. Distillates produced in the cracking process by heating under superatmospheric pressure to produce gasoline using as charging stocks
   (*a*) Crude oils
   (*b*) Crude oil residua
   (*c*) Distillates from crude oil distillation.
5. Residua produced by the same cracking process.

The finished fuel oil may be any of the above products, or mixtures of one or more of them.

CRUDE OIL, PER SE.

Under this classification no processing is ordinarily required, provided the crudes after settling are sufficiently free of water and sediment to allow their use under existing operating conditions and/or specifications. Usually crudes containing little or no gasoline with a high sulphur content and not adapted to asphalt manufacture constitute the source of such fuel. Occasionally, where due to traces of light material, the flash is below specifications it is necessary to reduce to test, which in most cases can be accomplished by heat exchange where waste heat is available.

* Consulting Chemist, The Texas Company.

PRODUCTS FROM DISTILLATION OF CRUDE OIL AT ATMOSPHERIC PRESSURE.

In "normal" distillation of crude oil at atmospheric pressure, the residuum left in the still or withdrawn from a flash drum or similar device, is considered fuel where the character of the crude is such that it may not be advantageous or economical to utilize it for a lubricant or asphalt. Again depending on the character of the crude and the possible value of the overhead fraction this residuum may be of sufficiently low viscosity to be used as a fuel oil unblended. If, on the other hand, the value or need of the overhead product is such as to necessitate obtaining the maximum yield thereof, the residuum remaining may be of almost solid consistency at atmospheric temperatures, in which case it is blended or cut back with a light product such as a virgin gas oil obtained in the early stages of the distillation or a cracked gas oil obtained from pressure stilling operations.

PRODUCTS FROM CRACKING PETROLEUM PRODUCTS WITH HEAT AND SUPERATMOSPHERIC PRESSURE.

In pressure distillation the products yielded are a light distillate consisting essentially of the material of gasoline boiling range, gas oil, and fuel oil, or coke. Whether fuel oil or coke is manufactured will depend on market conditions. Provided the former is manufactured, it may be used as produced from the pressure stilling units or can be blended as in the case of reduced crude oils. Where distillates are not available for blending the viscosity of the cracked residuum may be reduced to the required figure by means of so-called "viscosity breaking." This viscosity breaking is accomplished by heating under superatmospheric pressure and is really a mild form of cracking.

As has already been indicated, any number of combinations are possible with products coming under these three basic classifications, the crude oil itself if too viscous may be "cut back" with either an uncracked or a cracked distillate; an uncracked residuum may be reduced in viscosity with either a cracked or an uncracked distillate; and a residuum from the cracking process may be cut back with either a cracked or an uncracked distillate.

A sudden demand for increased supplies of fuel oil would necessitate the selection and processing of heavy crudes giving higher yields of fuel oil or the charging of larger quantities of light crudes so as not to interfere with the supply of other petroleum products. This, however, would result in the production of large quantities of straight-run gasolines which are usually not suited from an anti-detonating standpoint for modern automobiles and would require reforming operations with attending losses, or addition of knock inhibitors.

As a result the manufacture of fuel oil by pressure stilling equipment gives a gasoline meeting market requirements from a detonating standpoint, and further provides the most economical utilization of our crude oil supplies which are not replaceable.

TECHNICAL ASPECTS OF FUEL OIL SUPPLY PECULIAR TO THE WEST COAST.

By J. B. TERRY.*

In a discussion of the technical aspects of fuel oil supply, it is, of course, necessary to consider briefly the history of the adaptation of petroleum oil to boiler use and to trace the changes in refining processes which have had a direct bearing on the grades of fuel oil produced.

In a comprehensive paper entitled "Oil Fuel" presented by Mr. Ernest H. Peabody before the International Engineering Congress, San Francisco, Calif., September, 1915, several important references to the early use of fuel oil, especially for marine boilers, are made. As brought out in Mr. Peabody's paper, in 1874 the Russian Government adopted oil fuel for all vessels of the Caspian Fleet, thus utilizing a residual (asphaltic) product which had formerly been disposed of by burning in pits. In 1893, Col. Nabor Soliani, of the Royal Italian Navy, presented a paper on "Oil Fuel for Marine Purposes" before the International Engineering Congress held in connection with the World's Columbian Exposition in Chicago, and in fact oil fuels of Russian origin were in actual use by the Italian Navy at this time, largely, however, in experimental equipment.

The early use of petroleum residues for boiler fuel in Europe had little if any influence on American practice for two reasons: First, coal was easily obtainable and, except on the Pacific Coast, relatively cheap; second, before 1900, the major part of American crude oil was produced in the Appalachian fields and was of such grade that relatively little material suitable for "smoke stack" fuel was obtained by the existing processes of refining, in fact coal was used in firing refinery stills, particularly because of its availability and economy.

About the beginning of the century, oil containing a relatively large proportion of residuum suitable for fuel, was brought in

* Chief Chemist, Standard Oil Company of California.

almost simultaneously in California and Texas; and in 1901 a special board of Naval officers was appointed by Rear Admiral George W. Melville, U.S.N., "to investigate the relative value of oil and coal as a fuel for Naval purposes." This board, under the direction of Commander (later Rear Admiral) John R. Edwards, carried on an exhaustive investigation and its report, published in 1904, is still considered the most comprehensive and valuable treatise of its kind. By the time this report was completed the production of a heavy crude oil in the Kern River Field in California had reached appreciable figures and various users of fuel such as the railroads, the Merchant Marine and operators of stationary engines had made considerable progress in its utilization. The growth of the use of oil fuel was so rapid that by 1913, the Southern Pacific Railroad alone was burning oil at the rate of 32,000 barrels daily. Pipe lines had been laid from the oil fields to tidewater and several refineries were built to handle the crude oil from the fields in the interior of the State. Throughout the period 1900 to 1910, gasoline was of relatively little importance so that the chief output of the refineries consisted of fuel oil, export kerosene and road oils and asphalts with minor quantities of distillate fuel (gas oil) and "stove gasoline." At the same time much of the heavier crude was burned as such or after a simple "topping" operation for the purpose of obtaining a safe flash point.

The demand for gasoline on the West Coast of course increased rapidly with the development of the automobile but this increased demand was taken care of without great difficulty by improved methods of distillation and by "stretching" the boiling range of the gasoline so that heavier fractions were included in the product. This sufficed until 1920 when the shortage of gasoline became acute and it was necessary to seek other sources of this fuel. The cracking process had been developed but almost no work had been done on the West Coast with a view to adapting it to California crudes. A number of experimental cracking units were constructed and, while this research received a temporary setback during the "oil flood" from the Los Angeles basin beginning in 1921, several systems were developed, all capable of increasing materially the yield of gasoline from a given supply of crude, and,

incidentally, changing the quantity and physical properties of the residue suitable for boiler fuel.

Until about 1929 the supply of fuel oil available for marine use—especially by the Navy—was not materially affected by the increase of cracking operations, because of the fact that not all refineries had found it necessary to install cracking units and because there was still on hand a tremendous volume of topped crude which had been stored during the flush production period of 1921 to 1924. This stored fuel under former conditions would have been sufficient to supply the demand for several years, but, because of the increased requirement for gasoline, coupled with the necessity for curtailment of crude production, it has become necessary to return the major portion of it to refineries for the manufacture of motor fuel. The result has been a rapidly increasing proportion of cracked residuum in boiler fuels.

Unfortunately, perhaps, fuel oil on the West Coast has until recently been graded on the basis of specific (or more properly "A.P.I.") gravity; thus the standard grades were designated as "14 degrees plus," "17 degrees plus," etc., and, while physical properties other than gravity were prescribed in many specifications, the various grades were usually sold on the gravity requirement alone although no especial difficulties were encountered in meeting other requirements such as viscosity, flash point, freedom from foreign matter and the like.

Typical straight run (uncracked) fuels corresponding to the various grades showed approximately the following properties:

	17 Plus.	*14 Plus.*
Gravity	18.2	14.9
Flash	220	250
Viscosity at 122 degrees F. (Say. Furol)	56	260
S & W (by centrifuge), per cent	0.1	0.1

It will be noted that these grades corresponded roughly to grades 5 and 6 of the specification prepared by the Bureau of Standards under the title CS–12–33 of the American Standards Association and also that they were superior to these as well as the substantially similar grades described as Bunker Fuels B and C of Federal

Specifications No. 2d, especially from the standpoint of viscosity. As a matter of fact this superiority was so marked that it is probable that no fuel was ever sold on the West Coast which even approached the limits set for "Bunker C" and most of it approached, if it did not equal, the requirements of the "Bunker B" grade.

The straight run residue of about 17 degrees A.P.I. gravity (which incidentally is about the average gravity of California oil after topping) is especially suited to modern cracking operations, yielding as it does nearly half its volume of satisfactory motor fuel, the remainder being available for boiler use. The cracking operation, however, has resulted in rather profound changes in the properties of the fuel especially as regards the relationship of gravity and viscosity as will be noted from the following table showing the properties of typical cracked fuels such as those now being marketed:

Gravity	11.2	9.3
Flash	260	270
Viscosity at 122 degrees F. Furol	54	146
S & W (by centrifuge), per cent	0.5	0.5

A comparison of these properties with those of the straight run fuels shown above indicates primarily that the gravity-viscosity relationship is radically changed and that fuels specifically heavier than water have relatively low viscosities which, other things being equal, is the criterion by which fuels must be graded.

The status of the fuel oil situation is such that there is no present indication of any possibility of returning to the old type of straight run residuum and it is only logical to predict that future production of residual fuels will contain increasingly large proportions of cracked stock, and that the tests shown above are typical of fuels which will be marketed by the refiners of the West Coast. This condition is, of course, brought about by the increasing demand for gasoline to which is added the necessity for the better utilization of our crude resources.

TECHNICAL ASPECT OF FUEL OIL SUPPLY FROM THE GULF COAST AREA.

By Dr. R. T. Goodwin.*

The production area contributing to the supply of fuel oil for the Gulf Coast embraces the States of Arkansas, Kansas, Louisiana, Missouri, New Mexico, Oklahoma and Texas. The quality of fuel oils available on the Gulf Coast necessarily depends upon the grade of crude oils processed at the refineries. Generally speaking, these crudes may be divided into four large groups, namely: the East Texas crudes, having low sulphur and high pour point; the West Texas crudes, having low pour point and high sulphur; the Mid-Continent crudes of mixed paraffin asphaltic base; and Coastal crudes of naphthenic base, mainly used for producing lubricating oils.

PIPE LINES AND REFINERIES.

These various crudes are gathered and delivered through a network of pipe lines to some 286 refineries, having a total daily capacity of 1,789,000 barrels. Of these 286 plants, 47 per cent are equipped with cracking units, which have a total charge capacity of 42 per cent of the combined crude capacity. The attached sketch shows the location of these various crude oil pipe lines, and also shows that the terminus of many of these lines is on the Gulf Coast. This same sketch shows the location of refineries and bunkering facilities in this area.

REFINERY OPERATIONS.

The modern method of refining crudes involves two major processes:

(*a*) The crude oil is distilled or topped, yielding gasoline with minor by-products, such as gas oil, and a fuel oil residue.

* Shell Petroleum Corporation.

(*b*) This residue may be subsequently cracked to produce gasoline and a cracked fuel oil residuum.

During the past few years, due to low priced crudes, method (*a*) of atmospheric distillation has been largely practiced in the area outlined on the sketch described above. Uncracked fuel oils have a relatively high viscosity for a given gravity, are free from solids and are easily burned after preheating.

The method of operation of cracking processes may be divided into two classes:

1. Cracking to low level or liquid residuum, and
2. Non-residuum operation, *i.e.* cracking to solid residue of coke.

The above classifications can again be divided into several divisions, depending on:

Gas oil or topped crude for charge stock;
Liquid phase or vapor phase operation;
High pressure or low pressure operation;
Limited cracking to break viscosity.

By utilizing method (1) there is produced about 41 per cent gasoline, 12 per cent gas oil and 36 per cent fuel oil. By utilizing method (2), or non-residuum, the gasoline yield is increased to 49 per cent, gas oil 14 per cent and the fuel oil is reduced to 7 per cent with a yield of about 70 pounds of coke per barrel input. The method selected for operation depends on several factors, such as gasoline prices, coke price, fuel oil price, type of cracking unit used, etc.

TYPES OF FUEL OILS.

By means of the above described topping or cracking operations, there are produced in the area under discussion, four different types of fuel oils, as follows:

(*a*) A straight reduced crude, having a high viscosity and usually a high pour point.

(*b*) A fuel oil composed entirely of cracked residuum, having a low viscosity for a given gravity and a low pour point.

(*c*) A blend of topped crude with a high viscosity and cracked residuum with a low viscosity to give a medium viscosity fuel oil.

(*d*) A cracked residuum run to a gravity of 10 degrees A.P.I. or lower, then blended with an overhead distillate (preferably a cracked distillate) to a gravity of about 12 degrees A.P.I. This results in a very low viscosity fuel oil.

The reduced crude fuel oils described under (*a*) have been supplied in the past because of the extremely low market price for crude oils and limited cracking facilities available. The reduced crude fuel oils rapidly disappear from the market as soon as the prices of crudes, and consequently price of gasoline, are increased. These higher prices lead to the production of a fuel oil, described under (*b*), which is composed entirely of cracked residuum.

In many refineries, the cracking capacity is not equal to their crude input, so two products are produced—a topped crude and a cracked residuum. A mixture of these two products results in a very satisfactory fuel oil, and one in which the viscosity and other properties can be closely regulated by blending. In still another type of cracking, the residuum is run to a gravity of below 10 degrees A.P.I. in order to obtain a maximum yield of gasoline, and the residuum is sold as a high-viscosity product or blended with a cracked re-cycle distillate or gas oil to reduce the viscosity.

The following table shows the physical properties of Bunker fuel oils (produced by six different refineries) in the Gulf Coast area:

FUEL OILS AVAILABLE—GULF COAST.

Samples	*A*	*B*	*C*	*D*	*E*	*F*
Gravity °A.P.I.	12.6	13.2	11.1	15.5	15.2	12.7
Vis. S.F. @ 122°F sec.	33	96	136	.....	107	140
Vis. S.U. @ 122°F sec.	.....	.....	.....	196	.....	.....
Flash P.M. C.C. °F.	182	198	202	166	198	245
Flash C.O.C. °F.	210	280	285	240	270	270
B.S. & W. (300.31) %	0.6	0.5	0.9	0.6	0.8	0.9
Water (300.12) %	Trace	0.1	Trace	0.1	0.3	0.3
Sediment (300.2) %	0.14	0.12	0.26	0.30	0.10	0.27
Water (300.12) plus sediment (300.2) %	0.14	0.22	0.26	0.40	0.40	0.57
Pour Point °F.	5	35	35	20	55	35
Sulphur (Bomb) %	2.01	0.78	1.21	1.24	1.25	1.57
Conradson Carbon Res.	10.4	9.3	5.7	7.8	9.9	11.9
B.T.U. per bbl.	18300	18675	18300	18225	18450	18350

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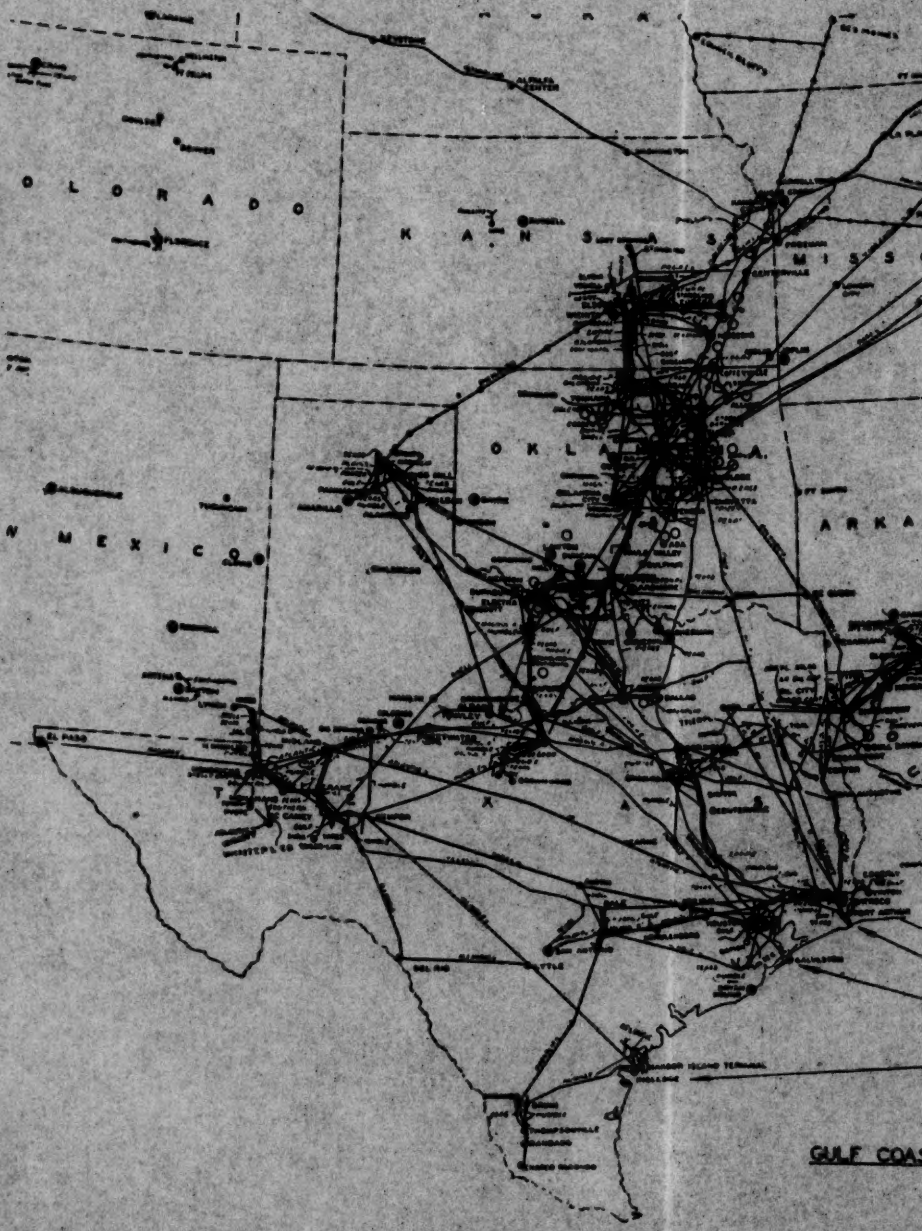
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GULF COAST AREA - SHOWING

CRUDE OIL LINE
GASOLINE LINE
REFINERIES
BUNKERS

The recent Navy fuel oil specifications can be met by a product composed entirely of cracked residuum, or a blend of cracked residuum and overhead distillate. In most cases it would be difficult to meet these new Navy specifications with a topped crude, except by blending with an overhead distillate. The overhead distillates have a higher market value than Bunker fuel and would result in a higher cost finished product.

CRACKED RESIDUUM FUEL OILS.

There has been a gradual increase in the percentage of cracked fuel present in marketed fuel oil blends, and in many cases the fuel oil is composed entirely of cracked residuum. Fuel oils from cracked residua have a number of advantages so far as the consumer is concerned. Cracked fuels are inherently excellent fuels for power purposes for the following reasons:

(*a*) The viscosity is low for any given gravity.

(*b*) There is a rapid break in the viscosity of a cracked fuel with increased temperature. This break usually occurs between 130 and 155 degrees F., so that the preheat can be limited to about 185 degrees F.

(*c*) Most cracked fuels will pour at 0 degree, while uncracked fuels may have pour points as high as 90 degrees F. This high pour results in difficulties in handling, especially for Navy use in cold water.

(*d*) The B.T.U. content per pound for cracked and uncracked fuels are about the same, but the cracked product is usually lower in gravity, thereby resulting in more pounds of fuel per gallon or barrel purchased.

FUTURE NAVY SUPPLY.

It is strongly indicated that the Navy must be prepared to burn cracked fuel oils in order to obtain an available supply at a reasonable price. Tests so far completed by the various Navy testing laboratories certainly indicate that cracked fuels are suitable for Navy use with slight modifications of burning equipment and operating conditions. The use of cracked fuels will very greatly increase both the quantity and availability of fuel for Navy purposes, and the product will continue to be produced as long as there is a demand for gasoline and other products of cracking.

EFFECT OF CHANGING REFINERY TECHNIQUE ON FUEL OIL SUPPLY.

By J. B. Rather.*

Intensive exploration of the private and public domain by the petroleum geologist and the " wild-cat " driller has in the past two decades established oil reserves of tremendous magnitude and economic value. The availability, and recognition of the advantages of liquid fuels have fostered rapid development in the technique and applications of oil firing. This growth has of recent years been most notable both in the marine and domestic fields.

In general it may be said that crude petroleums as produced are unsuitable for use as fuels without some processing, although some comparatively small production of crudes of the asphaltic type may exist to which this generality may not apply. The supplies of such oils are, however, so limited that their effect upon the fuel oil market structure is negligible. Being for the most part processed products, the petroleum refiner is basically identified with the economic production of fuel oils. The increasing usage of liquid fuels and the potential market demand for quality products of this class is causing much thought to be given to production of these once, in part, secondary refinery products.

The two major considerations which directly govern fuel oil manufacture are the type of crude oil supply and the processing equipment available to the refiner. As to the first mentioned factor, some crude oils of the asphaltic type are preeminently suited for economic use as fuels. Negligible in lubricating fractions and difficult to handle in cracking for gasoline, these oils rightfully constitute a considerable proportion of the bunkering fuels supplied today. On the other hand, considerable quantities of crude oil are produced, the use of which as fuels would constitute a serious waste of natural resources.

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Brief explanation of this statement would not be amiss at this point. Crude oils are extremely complex mixtures of an almost infinite number of hydrocarbon components which, in the present state of refining technique, are not individually separable. However, they may be segregated into three important characterizing groups, namely paraffins, naphthenes and asphalts. Crude oils are then classified according to the predominating subdivision present in its composition.

Under present conditions the heavier fractions of paraffinic crudes are the chief source of high-grade lubricants. Naphthenic crude fractions are the source of many low duty industrial lubricants, and of non-lubricating oils of special properties. The present known reserves of crude oil of these types, while large, are admittedly limited and it is an issue of national importance that they be refined for the maximum in products of economic value. Crude oils also carry straight run gasoline, burning oil, and light fuel oil fractions in varying proportions for which there exists a definite consumer demand. Obviously it is in the interests of conservation to process in such a manner that the maximum yield may be obtained of products for which a demand exists.

The gasoline and burning oil or kerosene fractions for the most part find a ready market and, in general, reach the consumer with much the same characteristics as recovered from the crude oil.

Such is not entirely the case of the distillate fuel oil fractions. At the present time there exists a fair demand for the distillate fuel oils as furnace oils, for domestic heating appliances, etc. This has developed largely within the last five years, and there is apparently a large potential market for this type of oil which will rapidly open with improving economic conditions. However, with modern refining equipment, this distillate fraction may be advantageously cracked for gasoline, and it is optional with the refiner in balancing his production with demand which method is used.

Gasoline has held a position of paramount importance in the petroleum industry for some years. The shortcomings of natural petroleum as a balanced raw material, which would supply the rapidly growing demand for gasoline in both quantity and quality, began to make itself seriously felt during the early days of the World War. At that time, fortunately, many of the vast oil

reserves of the present day were as yet unknown, and considerable effort was exerted by some of the larger members of the refining industry to develop methods whereby the percentage of gasoline recoverable from crude oil could be increased. As a solution of the problem, the Burton Process, the first commercial cracking process, became a factor of economic importance about the year 1915. Perhaps some idea of the far-reaching influence the introduction of the cracking process has had upon the utilization of crude oil may be obtained by reference to Table I. The statistics presented are prepared from data presented in "Petroleum, Facts and Figures" published by the American Petroleum Institute, and "Oil, Its Conservation and Waste" by James H. Westcott.

TABLE I.

Year	*Per Cent Cracked Gasoline in Total Gasoline Produced*	*Per Cent Gasoline Recovered from Crude Oil*
1918	13.5	21.6
1920	13.9	22.5
1922	17.9	24.0
1924	16.9	28.5
1926	31.0	36.1

The traditional period covered by these statistics indicates the degree to which the industry as a whole turned to the cracking process. This trend definitely indicates a curtailment in the percentage of natural distillate and residual fuels marketed as such. The rapidly increasing quantity of petroleum consumed in production, however, even with the decreasing percentage of fuel oils recovered therefrom, has been sufficient to afford adequate supplies in conjunction with the crude oils primarily produced for fuels. The ability of the cracking process to extract from crude oil a higher percentage of gasoline, the product of primary consideration, has placed it foremost among the influences for conservation.

How this industrial development has affected the supply of fuel oils may be appreciated by specific reference to the records of a large Gulf Coast refining organization. In 1916 the total production of marketable fuel oil was derived from topped crudes, while at the present time the output consists entirely of cracked

residua, the heavy oil residue remaining upon completion of the cracking reaction. These oils are in general characterized by specific gravities high in relation to their viscosities. During the period from 1916 to the present the gravity of the fuel oil has shown a year by year increase from a weight of 7.73 pounds per gallon to a present weight of 8.16 pounds per gallon. In quantity, this fuel represents approximately one-third the volume of natural fuel oils which would be available if not cracked for gasoline.

The overall results of changes in refinery technique upon fuel oils has been a diminution in the quantity of distillate fuel oils available from crude oil and a substitution of lesser quantities of cracked fuels of Bunker classification. This, however, has effected conservation of national petroleum resources as a whole, which is highly desirable.

Some degree of prejudice was early built up against the use of heavy cracked fuel oils. Difficulties experienced with sediment separation in the fuel tanks and burner difficulties contributed to considerable dissatisfaction on the part of some users toward these products. Concerned mainly by the urge for gasoline, a great deal of thought was not early given to the difficulties which the casual consumer might encounter in using this material.

The rapidly increasing demand of recent years has led to consideration of this condition, and fuller appreciation of the position cracked fuel oils might assume upon the market. As a result, properly processed cracked fuels of the present day are rather to be preferred. They are characteristically higher in calorific value than the virgin products, gallon for gallon, and generally have comparatively superior viscosity-temperature relationships. Bunker fuels of 0 degree F. pour point are obtained from crude or distillate fuel oils of low paraffinicity when cracked. The increasing fund of knowledge concerning cracking reactions, accumulated through experience, has lead to more general recognition of the processing factors which affect fuel oil quality. Considerable thought has been given this feature in the design of modern cracking equipment. It may truly be said that properly processed cracked fuels are in all respects the equal of uncracked fuels of similar classification.

A general conclusion may be drawn to the effect that the steadily increasing specific gravity of fuel oils reflects the more complete and advantageous processing of our crude resources. As long as gasoline remains the dominant feature in the petroleum industry, cracked residual fuel oils will be a factor in the fuel oil market, probably in increasing proportion as the normal increase in gasoline consumption develops.

What the picture may be five years hence is difficult to predict. The increasing use of Diesel power and the demands upon crude oil for an entirely different type of major product, which again most probably will be a product of cracking, would ultimately change the nature of the entire category of cracked petroleum products.

The history of the petroleum industry has been one of continual change and improvement both in quality and yield of useful products recovered from crude oil. It, therefore, may be safely predicted that the future demands of the consumer will be met by improved technique and processes designed for the adequate, economic, and satisfactory supply of processed petroleum products.

TECHNICAL ASPECTS OF FUEL OIL SUPPLY PECULIAR TO THE EAST COAST.

By A. E. Becker.*

Sources of fuel oil supply on the East coast are diverse. Not only do local refineries obtain their crudes from many different fields but much of the fuel oil distributed along the Atlantic Seaboard comes direct from refineries and/or producing fields of the Gulf coast, the Mid-Continent area, California, Mexico and South America. The physical characteristics of the crudes available from these fields vary widely. This necessitates different handling at the refineries. In addition gasoline demand in the Eastern part of the U. S. is large, which results in fuel oils which contain relatively high percentages of stocks from cracking operations.

Thus the fuel oil available on the East coast is derived from each of the five main classifications given in Mr. Mackenzie's paper. The net result is that there are no technical aspects which can be considered as peculiar to this section of the country. Any peculiarities of fuels available along the Gulf or West coasts would at times also be encountered in supplies purchased at Atlantic seaports. By solving the difficulties incident to the use of the varied types of fuel oil on the East coast it is quite likely that problems peculiar to fuel oils available at other localities will also have been met.

As already indicated the demand for gasoline is largest in the densely populated Eastern section of the United States. To supply this demand economically it is necessary that cracking operations be applied to all virgin gas oils, all crudes and all crude residua from atmospheric distillation that are suitable for the purpose. Those not suitable for cracking are usually of higher viscosity than is permissible for bunker fuels. The only economically available fluxes are the cycle gas oils and residua from

* Standard Oil Development Co., New York City.

cracking operations. Consequently the present supply of fuel oil on the East coast contains a considerable percentage of such stocks. Moreover, this percentage is likely to increase rather than decrease as demand for gasoline increases and as overproduction of crude decreases.

This need cause no alarm as present supplies of fuel oil are being successfully utilized by trans-Atlantic liners and freighters as well as by industrial plants of all kinds. Due to high specific gravity such oils contain a higher B.T.U. content per gallon, and contrary to some popular beliefs burn just as well as straight-run residua. Engineers need only familiarize themselves with the peculiarities of this type oil and the limitations under which it should be used.

Residua from cracking operations are often heavier than water. It is advisable to cut such stocks to the desired gravity for systems designed to use fuel oils lighter than water, so that any water entering storage tanks will settle to the bottom. It should be pointed out, however, that there is no inherent reason why fuel oils heavier than water could not be used successfully if supply systems were designed so that the oil would be taken from the bottom of storage tanks and any water contamination removed from the top. Such a system might have some advantages; for example, any water condensed from tank breathing would float rather than slowly settle through the oil.

Deposition of sludge in storage tanks is of particular importance to the Navy because of the necessity of storing fuel oil at Naval fueling stations for long periods of time. This settling tendency is associated with the presence of water and we have reason to believe that the higher the sediment by extraction the greater will be the tendency for sludge to settle in storage tanks. While sediment by extraction was formerly quite high for some residua cracking operations in general have changed so that today trouble from this source is much less likely to occur.

As a further precaution against such difficulties the oil should not be heated too high. For efficient pumping it is customary to reduce the viscosity by using pumping temperatures of 90 degrees F. to 125 degrees F. Heating coils should be adequate so that

there will not be local overheating, the other alternative being the use of lower viscosity fuel oils.

Atomization temperatures are in general more critical than pumping temperatures. Where steam can be used atomization is a relatively simple matter. For installations dependent upon mechanical atomizers it is necessary, however, to heat the oil high enough to reduce the viscosity sufficiently to obtain proper atomization. In doing this it is essential to maintain what is known as the viscosity-flash relationship; that is, the temperature at which the oil has a viscosity low enough to permit good atomization must be at least 20 degrees F. to 40 degrees F. lower than the flash point. Otherwise coking in the heating coils may occur.

Trouble from coking of burner tips caused by burning back into the nozzle may also develop unless proper precautionary measures are taken. The burner should be set so that the tip of the nozzle will not be as deep in the furnace. In general it is also desirable to increase the turbulence of the air supply as well as the amount of air around the root of the flame. The latter can be accomplished by using appropriate slots in the flame cone or shield.

Theoretically fuel oils from cracking processes should have a lower combustibility factor; that is, they should require a longer flame travel. As a matter of fact there is a dearth of information on this point. Technologists are accustomed to think in terms of the carbon-hydrogen ratio but the size and stability of the hydrocarbon molecules or aggregates have much to do with flame travel. The field is a fruitful one for research.

In conclusion it is safe to say that the most characteristic feature of the heterogeneous fuel oil supply on the East coast is the fact that it must contain a considerable percentage of stocks from cracking processes. In preheating such fuels it is essential to avoid shock heating which has a tendency to decompose some of the more unstable constituents. Where possible large heating surfaces and low steam pressures should be used to prevent such local overheating. Most burner preheaters are designed for heat transfer rates of 20 to 30 B.T.U.'s per hour per square foot per degree Fahrenheit of mean temperature difference, which rates are per-

fectly safe; preheaters using rates of 40 to 50 B.T.U.'s are apt to prove troublesome.

Where it is impractical to use safe heat transfer rates the alternative is to use a fuel oil of lower viscosity, thus avoiding the necessity of heating to as high temperatures. This can be done but will result in a more expensive fuel.

FUEL OILS AVAILABLE IN COMMERCIAL MARKETS IN FOREIGN PORTS.

By O. McCormick.*

Whilst the United States is by far the largest petroleum producing country, its consumption of fuel oil is also far greater than that of any other country and the quantity of different grades of oil fuel exported from the United States has decreased considerably of late. The result is, therefore, that countries abroad depend to an increasing extent upon other producing countries for their supplies of oil.

Outside of the United States of America, which produces over 60 per cent of the world's total supplies, the main countries contributing to the production of petroleum oils are, in order of present output, Russia, Venezuela, Roumania, Persia, Mexico, Dutch East Indies, Colombia, Argentina, Trinidad, Peru, British India, Poland, Sarawak, Egypt and Japan. In the near future Irak will prove an important addition to this list. Petroleum is certainly found in other countries also, but to such a limited extent that it is entirely consumed in the immediate locality and thus scarcely need be considered in this article.

Oil fuel forms a large proportion of almost all crude oils. At one end of the scale we have the clear light stove oils or furnace oils having a boiling range which is just above that of kerosene. Then there are various distillates and blends which are used either as Diesel fuels, or for domestic and industrial purposes. Finally there are heavier oils still, generally the residues from distillation and cracking processes, which are usually viscous liquids of asphaltic or paraffinous type, according to the base of the crude. The quantity and quality of each grade of fuel which can be extracted depends upon the origin and, therefore, the chemical composition of the crude oil treated, and also on the method of refinery working which is necessitated by the commercial requirements of the extracted products.

* Asiatic Petroleum Co., Ltd., London.

In most countries the first fuel oils known were of American origin, but with the advent of new production areas frequently better situated geographically, supplies can often be more economically shipped to the marketing centers from countries outside the U. S. A. While less than 10 per cent of the United States oil fuel production is exported, American oil is obtainable to some extent in every continent in the world, although its availability in Africa and Australasia is very limited.

In European markets, United States fuel is being imported in decreasing quantities and the major sources of supply generally speaking are now Venezuela, Roumania, Persia, Mexico and Russia, and to a lesser extent Trinidad and Poland. In North Africa naturally enough the majority of the supplies originate from Roumania, Egypt and Persia although fuel is also laid down from Venezuela. West Africa is conveniently situated for Trinidad and Venezuela while South and East Africa draw almost their entire requirements from Borneo and Persia.

In Asia, competing with California fuels, are those from Persia and the Dutch East Indies and so on, while naturally the indigenous production from Burma and Japan caters for a portion of the trade in the respective areas concerned. In Australia by far the greater part of the oil fuel consumed comes from Borneo, with lesser quantities from Persia and occasional deliveries from California.

So far as the South American countries are concerned, their requirements are practically entirely met from their own production with occasional importations from California or from Mexico to conveniently situated ports.

Oil fuel is at the present time used for the generation of heat and power in a multiplicity of industries of various kinds. By far the largest individual offtake, however, is for bunkering steamers and motor ships. As a consequence of this huge bunker offtake large fuel depots have been erected within comparatively recent years at strategic points on the main trade routes, such as the Canary Islands, Panama Canal, Curacao, Port Said, Aden, Cape Town and Singapore and enormous business is also done at the terminal ports of the various transoceanic liners, *e.g.*, in America, Germany, France, Italy and the United Kingdom.

In order to minimize the fire risk it has been practically universally agreed to specify a minimum flash point of 150 degrees F. for all grades of oil fuel supplied to ocean going vessels, although variations from this are sometimes encountered in the case of certain Admiralty specifications which stipulate a minimum closed flash point of 175 degrees F. Apart from this the actual properties of bunker fuel vary widely according to the origin of the oil. The thickest grade commercially available is generally manufactured to fall within the limits of the United States Navy Department Bunker Fuel Oil "C" with a maximum viscosity of 300 seconds Saybolt Furol at 122 degrees F. In the case of certain crude oils it is convenient for the refiner to turn out a fuel oil well below this viscosity limit; in other cases a viscosity modification is enforced due to inadequate heating facilities on board the vessel concerned or the waxy nature of the fuel.

Most of the fuel oils available in European and South American markets are prepared from crude oils which, generally speaking, give residues of a type comparable with those of the average American oil. It is perhaps rather stretching a point to speak of an "average" fuel oil when referring to a country with such wide and varied resources as the United States, but this particular reference as applied to bunker fuels for oil fired steamers is intended to convey those petroleum residues having a viscosity between about 30 and 300 seconds Saybolt Furol at 122 degrees F. and gravities lying between about 10 and 20 degrees A.P.I. Partial exceptions to the foregoing rule are the fuel oils from Persia and Russia which, generally speaking, are of greater fluidity than those from, say, Venezuela and Roumania. In the Far East, however, where fuel oils originating from Borneo, Sumatra, etc., are encountered a marked alteration is observable in the viscosity although the specific gravity is still as a rule between the rough limits quoted above. It is the exception rather than the rule for a furnace oil of Borneo origin to have a viscosity in excess of 30 seconds Saybolt Furol at 122 degrees F.; frequently in fact viscosities as low as 50 seconds Saybolt Universal at 100 degrees F. are encountered. While these fuels appear strange at first sight to engineers accustomed to using those available in the Western Hemisphere, their low viscosity and comparatively high calorific value make them extremely easy and economical to use.

Many companies grade their bunker fuel oils on a viscosity basis for reasons which are obvious to the purchaser. The other most important tests for the suitability of a bunker fuel are flash point (an exact knowledge of which is immaterial providing it is not below the legal limit, a point which is of course attended to by the supplier), water content and sediment, both of which are commercially governed by the limits of the U. S. Bunker "C" Grade specifications.

The preceding three paragraphs have dealt primarily with bunker fuel for burning under boilers. The increase in Diesel tonnage built during recent years, however, makes the fuel for internal combustion engines at least as important at the present day as boiler fuel. Strictly speaking any oil which can be made to operate a Diesel engine is entitled to be classed as a Diesel fuel, but since in practice there are very few engines particularly for marine work which can consume heavy residual fuels, most marine Diesel oils consist of distillates of the stove oil type or blends of distillate with residual fuel. In some cases light residual fuels themselves are employed but seldom does the viscosity of these exceed 120 seconds Saybolt Universal at 100 degrees F. Just as the fuel oils of the Far East differ from those of American origin so do the Diesel oils differ somewhat in analysis from those to which we are accustomed. A Beaume gravity of 22 is low for an American Diesel oil but it is quite normal for those of the Borneo type which are marketed in Australia. Some Diesel fuels from the Dutch East Indies have in fact gravities as low as 17 A.P.I. but their viscosity is frequently below 100 seconds Saybolt Universal at 100 degrees F. and they are excellent marine Diesel oils in every way.

FUEL OIL RESEARCH AT THE NAVAL RESEARCH LABORATORY.

By P. Borgstrom, R. D. Norton and O. I. Lewis.

The aim of the fuel oil research at the Naval Research Laboratory was the study of commercial fuels being produced in this country and to compare these with the fuels in use by the Navy. Many commercial fuels at that time were the result of various cracking processes used in the industry while the fuel purchased by the Navy was hoped to be "straight runs." The initial efforts of the Naval Research Laboratory were concentrated on the physical properties of the samples supplied by the oil companies to obtain as soon as possible the desired constants and to make the desired blends. On the completion of this work the fuel oils were studied chemically and the information given in this paper is largely from the latter viewpoint—namely that of the organic chemistry of the fuel oils. The work at the Naval Research Laboratory was begun under the direction of Lieutenant Commander W. H. Osgood, who had been in touch with the fuel oil situation of the Navy, as well as the developments in the oil industry. Through his personal contacts with the different oil companies, the original samples were collected for the research work at this laboratory.

In collecting any series of samples it was advisable to obtain at least drum samples of approximately 50 gallons when possible. The variety of samples obtained by Lieutenant Commander Osgood was not as large as he desired but those he did obtain gave a good cross section of the type of residuums being produced by the major refineries that could be blended to make commercial fuels.

These samples, which arrived at this laboratory during the late spring and summer of 1931, were stored on their sides in racks. Samples were drawn from these drums immediately for certain of the physical data to be used in connection with the work. The

following table gives a summarized picture of the samples available at this laboratory and their sources:

Location	*Cracked*	*Straight Run*	*Blends*	*Gas Oils, etc.*
California				
Los Angeles	16, 24, 27, 27—A 33, 17, 25.	15, 26, 32	28, 31, 44	18, 29, 34, 35
Signal Hill		45		
Ventura		21, 22		19, 20
San Joaquin Valley		30		
West Texas	14	12, 13		10, 11
Gulf Coast		37		
Mid Continent	38	36	39	40
Venezuela	8, 9			7
Navy Fuels			3, 4, 41	
Navy Diesel Oil				23

Due to the fact that many of these samples are not the typical residues produced by the refineries and should not be considered as the residuums ordinarly produced, the name of the company producing them and the type of equipment used is omitted. Also, refinery practices have changed greatly in some plants since these were produced, and therefore these samples may not be typical residues now being sold as fuels.

The samples used in this study were analyzed by known methods when available. The methods used are as follows:

Gravity: A.S.T.M. hydrometers see A.S.T.M. method D–287–33.

Viscosity: See A.S.T.M. method D–88–30.

Analysis: Carbon and hydrogen—Electric combustion furnace using special catalyst allowing the use of oxygen throughout the combustion.

Sulphur—Burgess–Parr sulphur peroxide bomb.

Nitrogen—Method by Poth, Armstrong, Cogburn and Bailey in Ind. Eng. Chem., Volume 20, page 93 (1928).

Molecular Weights: By a cryoscopic method using naphthalene as solvent.

Grain Size: Using hexane as solvent and fritted glass filters supplied by Eimer and Amend of different porosity to filter out the insoluble material.

Carbon Residue: Conradson method. See A.S.T.M. D–189–30.

Each of the above methods, when not standard, were checked with known materials as near those supposed to be in the fuel oils as possible. For grain size the filters were checked for average deviation and accuracy of method.

As the gas oils and kerosenes were used primarily as blends, the constants determined on them were less than on the fuels and are therefore given separately in Table I. The fuels are given in detail in Table II.

The first fuel oil used by the Navy would probably now be called "straight run." The original hydrocarbons of the crude oil after going through the process of refining emerged with minimum damage or alteration and were sold as fuel oil. If this resulting residue was too viscous for the trade, it was blended with kerosene or gas oil to the necessary viscosity and it should be remembered that the gas oil used for blending was also a "straight run."

As the demand for gasoline increased, and when the anti-knock rating appeared, it was necessary to change the methods of refining. It was found that unsaturated hydrocarbons gave better gasolines and to obtain them the charging stock was treated much rougher by increasing the temperature as well as pressure. As a result of this process known as "cracking," a new type of oil appeared. The heavier part was sold as fuel oil and the gravity of which reached 10 degrees A.P.I. and less. These cracked residues introduced a new problem for the user, especially for the Navy, as emulsions would form readily, since the fuel had nearly the same density as water, and also, when this heavy cracked residue is blended too far with a gas oil, the resulting fuel may be unstable. This would especially be so when the diluent was a saturated hydrocarbon of the type C_nH_{2n+2}.

In any tabulation, the fuels can be arranged as to composition (*i.e.*, carbon, hydrogen, etc.), and also as to the viscosity at a definite temperature, and as to the density at 60 degrees F. The fuels studied at this laboratory are arranged according to specific gravity in Tables I and II, and as can be seen the gravity of the fuel oils ranged from 0.30 to 28.2 degrees A.P.I. while the gas oils and kerosenes ranged from 27.1 degrees to 44.1 degrees A.P.I. It is interesting to note that the heaviest fuel in Table I is heavier

than the lightest fuel in Table II, that is, a gas oil to be used as a diluent can be heavier than a fuel oil from another field. The percentage composition, given in Tables I and II, are on the dry basis. The fuels as received at this laboratory showed but a trace of water, except for samples 3 and 41, which were from Naval vessels with fuels of a West Coast origin.

In the discussion of the hydrogen-carbon content of the fuels a term called the hydrogen carbon ratio is used. This term, H/C ratio, is calculated by dividing the percentage of carbon in the fuel by 12 and the percentage hydrogen by 1.008 and then dividing the value for the carbon into that for hydrogen, thus benzene which has a percentage composition of 92.75 for carbon and 7.75 for hydrogen gives $\frac{92.75}{12}$ or 7.69 atoms carbon and $\frac{7.75}{1.008}$ or 7.69 atoms of hydrogen, and this results in a H/C ratio of $\frac{7.69}{7.69}$ or 1 for benzene. For aliphatic hydrocarbons of the paraffine series this H/C ratio is slightly higher than 2 depending upon the length of the carbon chain while for the aromatic series it is unity or less than unity if condensed rings are considered. The heavy fuels studied in this laboratory have been considered in connection with this value, the hydrogen carbon ratio, and it is seen from Tables I and II that as the specific gravity becomes greater this value decreases and approaches unity while the gas oils have a H/C ratio of 1.99 to 1.69. The heavier the oil the smaller this value, thus, sample 34 from the Los Angeles field has a H/C ratio of 1.69, while the lightest fuel oil 36, from the Mid Continent field, has a H/C ratio of 1.77. It is interesting to note that the average molecular weight of 34 is 214, with a viscosity of 38.0 S.S.U. at 122 degrees F., while fuel 36 on the other hand has an average molecular weight of 419, and a viscosity of 151.2 S.S.U. at 122 degrees F. This shows that one oil having less precentage of hydrogen can be sold as a gas oil from one field while from another field it can be sold as a fuel oil. Comparing fuels 7 and 18 of Table I, it is seen that a fuel may have a lower distillation curve, a lower average molecular weight, and also a higher specific gravity. The H/C ratio shows that oil 7 is more aromatic in nature, having a H/C

ratio of 1.772, while 18 has a H/C ratio of 1.992, nearly that of a paraffinic hydrocarbon. These oils should have different burning characteristics.

It is interesting to examine the analysis of fuels that were used from 1916 to date. For instance in 1916, one fuel which was supposed to be Mexican crude supplied by one of the larger oil companies had a viscosity of 370 S.S.F. at 122 degrees F., a specific gravity of 0.976 and had a H/C ratio of 1.53. Analysis of other crudes used as fuel oils about 1918 and 1919 give a H/C ratio of 1.6 to 1.7. About 1919 there were three fuels supplied by an oil company that were rated as Bunker A, B and C yet the H/C ratio varied only from 1.74 to 1.70 while the gravity varied from 0.936 to 0.956 and the viscosity at 122 degrees F. from 35 to 115 S.S.F. In 1920 to 1924 fuels were sold that had a H/C ratio of 1.55 to 1.70 with a few as low as 1.45. As cracking came more and more into use, the H/C ratio dropped to approximately 1.45 to 1.60 when the specific gravity remained below 0.98. During this time usable fuels having a specific gravity greater than 0.98 were being sold that had a H/C ratio as low as 1.25 and 1.15.

In referring to Table II, it will be noted that the H/C ratio increases as the specific gravity decreases and that the oils having a H/C ratio of less than 1.5 were all cracked residues or blends. These blends were probably from cracked residues though this laboratory has no information as to the residues used. The straight run residues have a H/C ratio of 1.77 to 1.56. The data in this table shows that two refineries using a crude from the same field, may produce fuel oils that are different. For example 27 has a lower H/C ratio than 24 but it is the more fluid oil. As a result of this analysis it can be seen that the treatment the hydrocarbons receive will influence very greatly the nature of the resulting product. Fuel 14 should be carefully considered because this oil has a H/C ratio of 1.323, a specific gravity of 1.000 and yet has a viscosity of 114 S.S.U. at 122 degrees F., hence it has the characteristics of a gas oil cracked to get all the lighter materials possible from it but giving a fluid residue.

In considering the H/C ratio of commercial fuels, it should be noted that a straight run from one refinery may have a higher H/C ratio than a straight run from another refinery. This dif-

ference may be due to the type of charging stock that is available at the refinery. One company may have a charging stock that is high in sulphur and nitrogen and carrying a fair amount of aromatic compounds. This charging stock therefore would have a lower H/C ratio and, at the end of distillation, the substance known as a straight run residue, would have a smaller H/C ratio than the corresponding residue from a refinery whose charging stock was of a paraffinic nature. When considering cracking, the resulting product will be dependent upon the nature of the cracking process used in the refinery, thus, one refinery may crack until the H/C ratio reaches 1.3 and then use a cracked gas oil to cut back to a viscosity such that it can be sold to the trade. Fuels that have been cut back with a hydrocarbon that is highly paraffinic in nature may find that on standing a deposit will appear and result in an unstable fuel in storage. It should be noted that very few fuel oils have been analyzed at this laboratory that have a H/C ratio less than 1.4. It might be pointed out that some fuels are being produced and readily sold that have a H/C ratio of 1.15 but these are not used by the Navy.

The H/C ratio can be used to calculate the percentage of the charging stock that may go to fuel oil if a certain fixed H/C ratio is set for the residue as well as a certain H/C ratio for the distillate. The product distilled over is called the overhead and should also include any carbon that may deposit during the cracking process and can be filtered from the residue. Assume in this problem that the charging stock has a H/C ratio of 1.7 and that the overhead desired should have a H/C ratio of 1.9 while the residue should have a H/C ratio of 1.3. This can be set up in two equations as follows:

(1) Carbon = C (in overhead) + C (in the residue).

(2) Hydrogen = H (in the overhead) + H (in the residue).

Assuming 100 as the number of carbon atoms to be considered, then

(3) 100 = C (in the overhead) + C (in the residue).

(4) $1.7 \times 100 = 1.9 \times$ C (in the overhead) + 1.3 C (in the residue).

Then

$$100 = C_o + C_r$$
$$170 = 1.9\ C_o + 1.3\ C_r$$

Solving this gives

$$0.6\ C_o = 40$$
$$\text{or} \quad C_o = 66.7$$

This shows that two-thirds of the carbon goes to the overhead and one-third remains as fuel oil.

It was the good fortune of this laboratory to have samples from one refinery of (*a*) the charging stock, (*b*) lightly cracked residue, (*c*) medium cracked residue, and (*d*) heavily cracked residue. The H/C ratio of the charging stock was 1.63 and the three products 1.46, 1.39, and 1.29 respectively. If the assumption is made that the overhead would have a H/C ratio of 2.0, 1.9, or 1.8 then the per cent remaining in the residue can be calculated by the above method. The results of these calculations are given below:

Severity of Cracking	*H/C Ratio*	*Per Cent of Charging Stock in Residue When H/C Ratio of Overhead Is*		
		2.00	*1.90*	*1.80*
Lightly	1.46	68.5	61.4	50.0
Medium	1.39	60.7	52.9	41.5
Heavily	1.29	52.1	44.4	33.3

The percentage of the charging stock remaining as residue will be dependent upon what H/C ratio is desired in the overhead. How to obtain the desired overhead and bottoms with the equipment of a refinery is not in the scope of this investigation.

The molecular weights of the fuels were determined by the cryoscopic method using naphthalene as the solvent because naphthalene melts at 80 degrees C. or 174 degrees F., which temperature is high enough to hold the fuels in solution. In Table II, it will be noted that the molecular weights for the residues, having the higher specific gravity, are less than for the lighter residues, thus, the residues which were definitely cracked or straight run can

be grouped in relationship to the H/C ratio and molecular weights as follows:

	Av. Mol. Wt.
1.097 to 1.13	296
1.30 to 1.49	376
1.50 to 1.77	407

The hydrocarbons in a cracking still if largely aliphatic in nature may lose hydrogen, the side chains or may break into smaller units and again recombine, and in this recombination ring formation may occur which will result in increased specific gravity. This change in density, when hydrogen is broken from the ring to form aromatic compounds or as rings are formed can be shown by a few hydrocarbons as follows:

	Formula	*H/C Ratio*	*Molecular Weight*	*Density*
Hexadecane	$C_{16}H_{34}$	2.12	226	0.775
Phenanthrene	$C_{14}H_{10}$	0.71	178	1.182
2–6 Dimethyl piperidine	$C_7H_{15}N$	2.14	113	0.849
2–6 Dimethyl pyridine	C_7H_9N	1.29	107	0.942
N–Butyl sulfide	$C_8H_{18}S$	2.25	146	0.839
Tetra–methyl thiophene	$C_8H_{12}S$	1.50	140	0.944

However, if the charging stock is highly naphthenic or aromatic in nature (a H/C ratio of 1.6) and the cracking process tends toward condensation of the rings then the resulting molecular weight may increase as the specific gravity increases. Sample 14 may be the result of such a process—it has a specific gravity of 1.000, fluid, and has an H/C ratio of 1.323. Fuels of this type may not be economically justified at this time, but they certainly would relieve the operator of many difficulties in handling if available at low cost.

In comparing the fuels, it is found that the fuels from the West Coast are higher in nitrogen content than those from east of the Rocky Mountains. For burning, this may not be a disadvantage, but it may cause other difficulties. The charging stock coming into a cracking still may contain both nitrogen and sulphur compounds and it is well known that many types of sulphur com-

pounds such as alkyl sulphides and disulphides have a tendency to decompose. As a result into the overhead will go hydrogen sulphide, mercaptans and other readily volatile sulphur compounds, leaving in the residue the ring sulphur compounds that are not readily decomposed. As a result the per cent sulphur in a cracked residue could readily be less than in the straight run from the same source. The information, as to the ease of decomposition of nitrogen compounds is limited. It is well known that, on oxidation, quinoline will lose the ring consisting of carbon only leaving a substituted pyridine. The same may well happen in a cracking still. In the study of the few samples available from the same companies having both straight run and cracked fuels, it was found that the per cent sulphur and nitrogen was 1.33 and 0.63, respectively, in the straight run residuum and 1.07 and 0.75 in the cracked residuum. This shows a tendency for lowered sulphur and increased nitrogen as the result of the cracking process. This should be investigated further by those who have available the same charging stock going to the two types of stills.

In studying these fuels from the analysis for carbon, hydrogen, sulphur and nitrogen and by using the average molecular weight as shown by cryoscopic methods, it is readily seen that sulphur and nitrogen compounds play a very important part in the makeup of the residues. Assuming one atom of sulphur or one atom of nitrogen in the molecule, these sulphur and nitrogen molecules may account for as much as 50 per cent of the residue. Therefore, the study of these heavy sulphur and nitrogen compounds are necessary to understand fully the nature of hydrocarbons in fuel oils.

In comparing fuels for Bunker use the stability of these fuels to the emulsion formation is highly important. Thus, why should one oil form a stable emulsion and another one not, even though the gravity is the same? In studying these N.R.L. samples it was found that the chemical composition of the fuel was more important than the source. Thus a fuel of 2 degrees A.P.I. from one field gave an unstable emulsion while one from another field of 14.5 degrees A.P.I. gave a stable emulsion.

Approximately 300 emulsions have been made, by various methods, and studied as to stability. In the study of emulsions of

Bunker fuels, the following three types were investigated. First, that of salt water shaken in; second, that of fresh water shaken in; third, that of water steamed in. For each type, three concentrations were made containing approximately 2 per cent, 5 per cent and 10 per cent water. To find the total amount of water that each oil would hold an emulsion was made by agitation of equal volumes of oil and water. After 24 hours the water held in each emulsion was determined by A.S.T.M. method D 95-27. About 5 months later another determination was made. From these samples it was found that the type of water or the way of introducing water into the oil had little bearing upon its stability, but that sea water emulsions seem to be less stable on long storage tests.

It was found that no one thing is the controlling factor in the stability of emulsions. Comparing straight run and cracked fuels it is shown that the amount of water held by straight run is less than that held by cracked fuels, and once an emulsion is formed straight run is less stable especially for the higher concentration of water. Determination of viscosity contributes slightly to the knowledge of the stability of an emulsion. Oils with a viscosity greater than 120 seconds Furol at 122 degrees F. has a greater tendency to form a stable emulsion than a less viscous oil. A fuel oil with the gravity less than 0.950 will hold only half of an emulsion of 9 per cent water, while in most cases it will hold all of the water of a 2 per cent emulsion. In most cases, oils with gravity above 0.950 will hold between 75 per cent and 100 per cent of the water contained in a 10 per cent emulsion. Of course, it must be taken into consideration that the heavier oils are usually cracked and more viscous. It was discovered that with few exceptions there is a direct correlation between the content of nitrogen and the stability of an emulsion. Oils containing nitrogen up to 0.17 per cent and averaging 0.14 per cent have held approximately 35 per cent water for the period of 5 months, while those containing nitrogen from 0.28 per cent to 1.10 per cent and averaging 0.72 per cent have held approximately 91 per cent water for the same period of time. This shows that the oils with low nitrogen have a tendency to form unstable emulsions. Whether nitrogen is a controlling factor or not cannot be determined definitely from

this work. It may be nitrogen plus certain gravity or viscosity factors that controls the emulsion formation and it would be necessary for further study in order to determine this.

Some of the oils with a density nearly that of water hold an emulsion readily. The water on separation would result in the formation of small globules throughout the oil. This will cause much trouble when the oil is heated for atomization, as the unequal distribution of water in the oil will cause an uneven fire, or extinguish the fire completely.

The viscosity of the fuels in Table II were studied over a long range of temperature. The data found are entirely too bulky for this paper and only some of the conclusions are given. The viscosity-temperature data when plotted on the ordinary charts used for this purpose do not give straight lines for many of the heavy fuels, consequently, it is questionable whether it is permissible to use data taken at one temperature and extrapolated to another. When the Navy requests that the industry supply the viscosity at certain temperatures it is desirable that the data be taken at those temperatures and not extrapolated from data taken at other temperatures. When the viscosity is desired at temperatures near the pour point, these especially should be determined experimentally. Thus, one fuel froze sharply at 62 degrees F. and yet was very fluid at 65 degrees F., and another gave a definite upward tendency 15 degrees away from the pour point. Definite conclusions cannot be drawn as to the kind of fuels whose viscosity are affected by the pour point since many of the samples are not fuels sold commercially. The data obtained in a cooperative study now being conducted by the Navy Department may give a clue to those fuels showing this tendency.

The grain size given in Table II is the per cent of the sample that is held by a fritted glass filter of a certain porosity when a fuel oil diluted with hexane is filtered through the crucible. The average size of the pores in microns for a No. 1 filter is 100-120, for No. 2 40-50, for No. 3 20-30, for No. 4 5-10. This study shows that the aggregates formed in hexane are large for some fuels such as 27 and 38, while for others the insoluble material in hexane is caught by No. 3 and No. 4 filters only. The straight run residues give less insoluble material than do the cracked

residues. These values should be compared with the carbon residues determined by the Conradson method, which are given in Table II. The similarity of these values with the hexane insoluble caught on a No. 4 filter should be noted.

The information given under grain size may be correlated in future work with a tendency of sediment formation and clogging of heaters. This cannot be expected from the one set of data given in Table II, but more information must be obtained with the same fuels studied under various conditions. Thus, fuels when heated in an atmosphere of oxygen give a larger percentage on a No. 4 filter than when heated in an atmosphere of carbon dioxide where there is but a slight increase over the unheated sample. The inference from this would be oxidation, but no noticeable change occurred in the molecular weight of the sample. Thus, samples as they become older show an increase in the per cent of insoluble material in hexane. Therefore, determination should be made at the approximate time the fuel is burned. Other solvents could have been studied but hexane was found to be satisfactory in that the sample dries to constant weight very readily. The sediment in the filters was readily soluble in benzol.

As the samples became older it became questionable if some of the determinations would be comparable to the findings with a fresh sample. Other tests were used in this study that are not reported here because of this fact.

Before closing, two other tests can be mentioned. The benzol insoluble as determined by extraction with hot benzol was 0.17 per cent or less for all the samples. The extraction was continued until the crucible became constant in weight. After becoming constant in weight, these crucibles were burned to remove any organic matter and were again weighed. This gave the ash that remained after the benzol extraction. This ash is much smaller than when the sample is ashed in a platinum crucible directly.

In the determination of sediment and water by the centrifuge, it was found that unless the sample to be centrifuged was allowed to come to 120 degrees F. before running the values may be high. As a result, the cups were put into the thermostat at 120 degrees F. and allowed to come to temperature, then thoroughly shaken,

Number	Source	Gravity A.P.I.	Gravity Sp.Gr.	Viscosity
34	Gas oil (30-36). Los Angeles basin crudes mixed.	27.1	0.892	
20	Gas oil (straw distillate 38-40). Ventura crude.	38.1	0.835	
23	Type sample of East Coast mixed diesel fuel.	33.8	0.858	
11	Gas oil (30-36). From reforming West Texas tops. West Texas crude.	33.6	0.857	
29	Gas oil (38-40). Mixed Los Angeles basin crudes (same as 27-A).	33.8	0.856	
35	Gas oil (38-40).	34.4	0.853	
7	Kerosene furnace oil. Venezuelan crude.	34.8	0.848	
10	Gas oil (38-40). From reforming East Texas tops. East Texas crude.	38.3	0.833	
19	Kerosene (Commercial 40-42). Ventura crude.	40.7	0.820	
40	Kerosene (40-42). Mixed Mid Continent crudes.	43.0	0.810	
18	Kerosene (Commercial 40-42). Mixed Los Angeles crudes.	44.1	0.806	

Number	Source
27	Pressure still (cracked) residue. Mixed Los Angeles basin crudes. (same as 27-A).
28	Pressure still (cracked) residue. Mixed Mid Continent crudes.
39	Blended fuel oil "D". Mixed Mid Continent crudes.
24	Pressure still (cracked) residue. Mixed Los Angeles basin crudes.
33	Pressure still residue. Los Angeles basin crudes mixed.
14	Pressure still (cracked) residue. West Texas crude.
25	Blended fuel oil, grade "D". Pressure still residue 71%, straight run residue 26%, stove oil 3%.Los Angeles basin crudes mixed.
9	Cracked blended fuel oil grade D, High viscosity. Venezuelan crude.
31	Blended fuel oil grade "D". From Los Angeles basin crudes mixed.
8	Cracked blended fuel oil grade D, Low viscosity. Venezuelan crude.
27-A	Pressure still (cracked) residue. Mixed Los Angeles basin crudes. 30% Santa Fe;33% Signal Hill;15% Huntington Beach;22 Torts Link.
16	Pressure still (cracked) residue. Mixed Los Angeles basin crudes.
17	Blended fuel oil "D". Mixed Los Angeles basin crude. Mixed consists of one third No. 15 and two thirds No.16 by mechanical stirring.
28	Blended fuel oil grade "D". Mixed Los Angeles basin crudes. (same as 27-A).
41	Mixed fuel oil grade "D", from U. S. Naval vessel. East Coast fuel.
30	Straight run topped residue. From San Joaquin Valley crude.
3	Average mixed sample of East Coast Fuel oil from U.S.S. Los Angles.
21	Grade "D" fuel oil. Straight run, not blended. Ventura crude.
13	Blended fuel oil, grade "D", 50% residue from topping West Texas crude, and 50% bottom.
44	Blended fuel oil grade "D". Mixed Los Angeles basin crudes.
4	Average mixed sample of East Coast Fuel oil from U. S. S. Wyoming.
22	Straight run (topped) residue. Ventura crude.
32	Straight run topped residue. From Los Angeles basin crudes (mixed).
45	Straight run unblended residue. Signal Hill crude.
26	Straight run (topped) residue. Los Angeles basin mixed crudes. (same as sample 27-A).
37	Straight run (topped) residue. Gulf Coast crudes (mixed).
12	Straight run. (Topped residue). 60% residue. West Texas crude.
15	Straight run residue. Mixed Los Angeles basin crudes.
36	Straight run (topped) residue. Mid Continent crudes (mixed).

TABLE I - CONSTANTS OF THE GAS OILS, KEROSENES, AND DIESEL OILS.

Gravity 60° F Specific	Viscosity 122° F		Analysis Carbon	Hydrogen	H/C Ratio	Nitrogen	Mol. Wt.	Distillation Temperatures °F Percent Recovered 10	50	90
[illegible]	33.0	[illegible]	85.63	12.35	1.690	0.11	214	446	[illegible]	495
[illegible]	36.6	[illegible]	86.11	12.72	1.758	0.08	225	473	[illegible]	562
[illegible]	34.5	[illegible]	86.52	12.99	1.738	0.04	203	438	479	564
[illegible]	35.3	[illegible]	86.61	13.14	1.806	0.08	215	476	[illegible]	613
[illegible]	36.5	[illegible]	86.47	12.96	1.784	0.07	222	457	[illegible]	657
[illegible]	31.2	[illegible]	86.47	12.79	1.760	0.01	173	395	[illegible]	499
[illegible]	30.0	[illegible]	86.42	12.66	1.772	Tr	168	[illegible]	[illegible]	458
[illegible]	31.1	[illegible]	85.92	13.31	[illegible]	Tr	160	377	436	339
[illegible]	30.2	[illegible]	85.96	13.61	[illegible]	Tr	175	[illegible]	434	[illegible]
[illegible]	30.4	[illegible]	85.75	13.92	1.930	0.02	176	[illegible]	430	460
[illegible]	30.6	[illegible]	85.77	14.35	1.992	Tr	179	[illegible]	438	470

TABLE II - CONSTANTS OF THE FUEL OILS STUDIED.

Gravity 60° F ° A.P.I.	Specific	Viscosity 122° F		Analysis Carbon	Hydrogen	H/C Ratio	Sulphur	Nitrogen	Mol. Wt.	Grain Size #1	#2	#3	#4	Carbon Residue
0.3	1.070	[illegible]	352.1	90.38	8.34	1.097	0.38	0.38	307	27.5	16.5	19.1	18.1	23.4
2.0	1.058	[illegible]	60.7	89.75	8.77	1.136	1.22	0.12	[illegible]	9.2	11.4	10.5	9.2	15.6
2.9	1.058	[illegible]	105.0	89.79	8.56	1.131	1.73	0.15	311	2.5	9.4	10.0	10.0	15.5
6.2	1.026	[illegible]	312.0	87.28	9.56	1.304	1.59	1.30	[illegible]	1.05	15.5	15.5	16.5	19.7
6.9	1.022	[illegible]	191.2	87.07	10.03	1.370	1.32	0.99	[illegible]	-	0.07	11.4	14.8	16.1
10.0	1.000	[illegible]	114.0	87.02	9.77	1.383	2.08	0.16	[illegible]	-	-	0.30	2.7	6.2
10.03	0.999	[illegible]	225.1	86.78	10.04	1.396	1.84	1.05	[illegible]	-	1.3	14.7	14.4	16.7
10.9	0.994	[illegible]	262.4	86.04	10.19	1.420	2.40	0.42	[illegible]	-	Tr	1.46	15.4	15.2
11.4	0.990	[illegible]	112.4	86.55	10.50	1.445	1.39	0.88	377	-	-	1.56	9.7	12.3
12.0	0.986	[illegible]	182.4	85.96	10.44	1.449	2.58	0.41	370	-	-	1.35	13.0	13.9
12.7	0.982	[illegible]	200.0	86.55	10.75	1.478	1.86	0.86	413	-	-	0.35	10.8	13.2
12.9	0.980	[illegible]	215.4	86.58	10.72	1.476	1.84	0.88	417	-	-	0.37	10.6	13.4
14.5	0.969	[illegible]	136.8	86.32	11.08	1.500	1.59	0.77	453	-	-	0.2	8.6	11.6
14.5	0.969	[illegible]	153.9	85.96	10.93	1.514	1.30	0.86	397	-	-	0.25	9.5	11.0
15.3	0.965	[illegible]	80.0	84.97	11.23	1.578	1.32	-	359	-	-	0.5	7.1	9.4
15.4	0.963	[illegible]	84.8	86.21	11.31	1.584	1.08	0.42	387	-	-	Tr	2.5	6.3
15.7	0.961	[illegible]	74.	85.70	11.24	1.576	1.39	0.44	366	-	Tr	2.6	6.7	9.3
15.7	0.961	[illegible]	223.7	85.50	11.96	1.669	1.96	0.44	377	-	-	1.1	5.5	9.6
16.5	0.956	[illegible]	169.8	85.45	11.98	1.615	2.53	0.23	326	-	-	0.1	2.8	7.9
16.8	0.954	[illegible]	85.6	85.90	11.53	1.605	1.46	-	381	-	-	0.08	5.5	7.9
17.1	0.952	[illegible]	19.8	87.00	11.30	1.566	1.39	0.17	306	-	-	0.13	3.9	6.3
17.1	0.952	[illegible]	124.4	85.77	11.52	1.604	1.73	0.60	418	-	Tr	2.1	4.5	8.7
17.6	0.949	[illegible]	73.7	85.62	11.63	1.624	1.52	0.66	[illegible]	-	-	0.14	5.9	8.3
17.8	0.948	[illegible]	68.8	85.54	11.71	1.630	1.39	-	387	-	-	0.23	2.1	9.9
18.2	0.945	[illegible]	65.0	85.52	11.66	1.626	1.30	0.65	377	-	-	0.1	0.0	7.5
19.0	0.940	[illegible]	365.0	86.97	12.10	1.670	0.34	0.11	371	-	-	Tr	0.2	2.3
19.3	0.938	[illegible]	240.1	85.53	11.98	1.668	2.33	0.16	381	-	-	0.1	0.6	5.3
20.3	0.932	[illegible]	49.3	86.05	11.74	1.625	1.16	0.96	388	-	-	0.2	4.8	3.3
20.2	0.[illegible]	[illegible]	151.8	86.30	12.81	1.789	0.51	0.13	419	-	-	Tr	Tr	2.9

and centrifuged. By this method, check results were obtained. Some samples if containing one-half per cent water or more required long centrifuging to get the water thrown out.

For the past few months the work at this laboratory has been concentrated on a cooperative study of fuels conducted by the Navy Department. This series consisting of eighteen fuels supplied by the contractors in tank car lots is designated as the "A" samples to differentiate from the N.R.L. samples. This study now being brought to a completion should give an opportunity to correlate the findings from the N.R.L. samples with fuels used in actual burning tests such as are being conducted by the Naval Boiler Laboratory and heater fouling now being studied at the Engineering Experiment Station.

This study can be briefly summarized as follows:

(1) That the hydrogen carbon (H/C) ratio can be used as an aid in identification of the treatment that a fuel oil has received in the process of production.

(2) The viscosity of the fuel at some definite temperature such as 122 degrees F. and the specific gravity at 60 degrees F. in connection with the H/C ratio will aid in identification of the kind of charging stock used.

(3) The analysis of the fuel will aid in location of the source of the fuel.

(4) The nitrogen content of a fuel affects the stability of the emulsions.

The ordinary physical tests as now used for the purchase of fuels by the Navy may not prove sufficient to differentiate a fuel for Naval purposes from one that can be used for other power plants. It may be desirable for the Navy in the future to purchase fuels on specification based upon chemical analysis. While this research has not pointed out definite tests, it has given certain indications as to the nature of the oils. It has been deemed of sufficient importance by the Navy to continue the research as to the nature of the commercial fuels so that the Navy will be cognizant at all times concerning any new development that may occur in the oil industry.

THE TENDENCY OF CRACKED FUEL OILS TO FORM DEPOSITS IN FUEL OIL HEATERS.

By Lieutenant Ralph R. Gurley, U. S. Navy, and Mr. J. G. O'Niell.*

It was at one time believed that the tendency of cracked fuel oils to form deposits in fuel oil heaters would be a serious bar to the use of this type of fuel by the Naval Service. The first attempt to burn a known cracked fuel oil on a capital ship resulted in complete clogging of the heaters in a phenomenally short time. Purchases of this type of oil were discontinued and an investigation begun to determine the cause of its behavior in the heaters and to develop a remedy, if possible. This investigation, which formed an integral part of the entire Fuel Oil Investigation undertaken by the Bureau of Engineering, was conducted at the Engineering Experiment Station at Annapolis.

During the course of the work at Annapolis fourteen cracked fuel oils (designated A-1 to A-14, inclusive), furnished by various refiners, were subjected to a series of tests, including a miniature Service Heater Test, a Pressure Heater Test, a Super Centrifuge Test, and several physical and chemical tests designed to determine the nature of the fuels and their reaction to heating under Service conditions. Some twenty deposits from ships' fuel oil heaters were analyzed by a special procedure devised to measure the oil, moisture, asphalts, free carbon, solubles, and insolubles. The same method of analysis was employed to study the sediments removed from the oils by the super centrifuge and the deposits removed from the miniature fuel oil heaters.[1]

The most striking development of the investigation conducted at the Experiment Station is the Super Centrifuge Test. In this test

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[1] The general characteristics of the fourteen fuel oils, as determined by standard methods of analysis, are tabulated in Table 1. The analyses of the fuel oil heater deposits received from the Fleet are compiled in Table 2. The constituents of the super-centrifuge deposits of the fourteen samples, A-1 to A-14, inclusive, are grouped in Table 3. In Table 4 are assembled the results of certain special tests and some other factors for ready reference in studying the curves of Figures 1 to 4, inclusive.

a one-gallon sample of the fuel oil, at a temperature of 250 degrees F., is centrifuged in a Sharples super centrifuge for one hour at 30,000 R.P.M. By this means all the sediment in the gallon of oil is effectively removed and is available for analysis and study in its native state. All of the components of the sediment, which normally are so scattered throughout the body of the oil as to defy analysis, are concentrated in this super centrifuge deposit and can be identified and measured. The value of a study of this sediment is believed to extend far beyond the limits of the investigation as conducted at this Station.

Examination of the super centrifuge sediment obtained from the fourteen oils tested indicates that there are two distinct types of sediment, namely, a comparatively dry, carbonaceous sediment and a sticky, gummy sediment. The most pronounced groupings under these two categories are: A-2, A-7, and A-8 of the dry, carbonaceous type, and A-6, A-9, A-10, A-11, and A-13 of the sticky, gummy type. Oils containing the latter type of sediment show a greater tendency to form heater deposits than oils containing the former type. This fact is especially noticeable in comparing A-7 and A-9. A-7 created very slight heater deposits, then only at a 300 degree F. oil temperature, whereas A-9 created excessive deposits at 200 degrees F.[2]

The Super Centrifuge Test is merely an accelerated settling test in which the force of gravity is increased many-fold. Therefore, if heater deposits resulted from ordinary deposition of the sediment carried by the oil, they would be some function of the total sediment obtained in this test. But, in the case of A-7 and A-9, above, the two oils have 20 and 18.2 grams of sediment per gallon, respectively, and give heater deposits of widely different values. Columns 2 and 3 of Table 4 indicate that A-2 and A-13 offer a similar situation. A-2 gave 14.2 and A-13 gave 11.6 grams of

[2] The tendency of the oils to form deposits in heaters was determined on a set-up consisting of three miniature fuel oil heaters operated in parallel under fixed conditions of pressure and temperature on oil and steam sides. Each heater contained three passes of a single ⅝-inch tube, fifty-four inches long, through which the oil flowed. All three heaters operated at the same rate of oil flow with different oil outlet temperatures. Steam flow was controlled to give oil outlet temperatures of 200, 250, and 300 degrees F., respectively. Steam temperatures as high as 530 degrees F. were encountered. After each run the tubes were examined for deposits which were removed and weighed whenever possible. The relative weights of all these artificially created deposits, based on sediment per thousand gallons of oil, are listed in Column 3, Table 4.

sediment by super centrifuge, yet A-13 showed by far the greater tendency to form fuel oil heater deposits. It would appear, for the moment, that the total sediment in an oil has little, if anything, to do with the tendency of the oil to form heater deposits. On the other hand, analyses of these deposits show quite definitely that it is the sediment originally in the oil that tends to clog the heaters. Some other factor must control the adherence of this sediment to the walls of the heater tubes. Comparison of heater deposition with appearance of the super centrifuge sediment suggests very strongly that the relative gumminess of the sediment is this controlling factor.

A comparison of the data on A-7 and A-6 furnishes the most vivid interpretation of the influence of the gummy characteristic on heater deposition. A-7, with 20 grams of comparatively dry, carbonaceous sediment, gave markedly less heater deposit than did A-6, which had only 5.2 grams of sticky sediment.

The most notable distinction between the chemical analyses of the two types of sediments is that those which appear carbonaceous contain lower percentages of water soluble sulphates than those which appear gummy. A study of Table 4 will show that, in general, heater deposits increase with increase in percentage of water soluble sulphates. The relation between these sulphates and heater deposition is further hinted by the analyses of the deposits from the vessels of the Fleet, listed in Table 2. It will be noted that the water soluble sulphate content is characteristic of the gritty deposits. Two deposits described as oily liquids contained sulphates, probably derived from water which had to be poured off before the analysis was made. The six remaining oily liquid deposits had no sulphates whatever. Since an oily liquid can hardly be considered an objectionable heater deposit, it may be said that water soluble sulphates are characteristic of undesirable fuel oil heater deposits.

Just why these water soluble sulphates should exercise control over heater deposition is not apparent. The explanation of their origin is also open to conjecture. It is believed, however, that their presence is subject to some control by the refiner and that, therefore, it will be possible for every refiner to produce cracked fuel oil that will not form objectionable deposits in fuel oil heaters.

In Figure 1 oils A-1 to A-14, inclusive, have been plotted according to total super centrifuge sediment and percentage of water soluble sulphates in the sediment. The points representing A-5, A-8, A-7 and A-2 have been joined by a dotted line. These four oils gave very slight deposits in the miniature heater test. A-11 and A-13, which gave almost identical heater deposits, are also joined together. On the figure the number under the sample designations indicates the relative tendency to form heater deposits. Where this number is omitted the oil did not create sufficient deposit to be weighed. Other oils than the A-group were not run in the miniature heater test and, therefore, do not have a relative deposit rating. Sample A-12 belongs on the line through A-7 and A-8 as regards heater deposits, but, supposedly, its water content (0.55 per cent) caused an increase in the percentage of water soluble sulphates over that encountered in A-7 and A-8. Disregarding A-12, a group of curves of the shape of "A" and "B" in Figure 1 can be defined as curves of constant heater deposition, the curves of greater deposit being farther from the origin.

The points marked S-1324 and S-1326 represent two cracked fuels previously tested by the Naval Boiler Laboratory. That Laboratory reported that S-1324 caused heater deposits of such magnitude as to render it unsuitable for Naval use. S-1326 also caused heater deposits but not to such an extent as to make it unsuitable for Service consumption. This oil was reported to be on the border line of suitability. Since the Boiler Laboratory runs its tests with actual Service heaters, its report has been accepted as the criterion of the amount of deposit which can be tolerated. Judging by the positions of these two oils on Figure 1, it would appear that Curve "B" closely approximates the allowable limit of heater deposition and any oil falling to the right of this curve would be undesirable. To simplify the statement of specification limits based on these curves it would probably be preferable to define Curve "C" as the limit. This curve is a hyperbola, so described that the product of percentage soluble sulphates by super centrifuge sediment (grams per gallon) is 40. The points marked "X-1" and "Bunker A" represent fuels in constant satisfactory use in the Service.

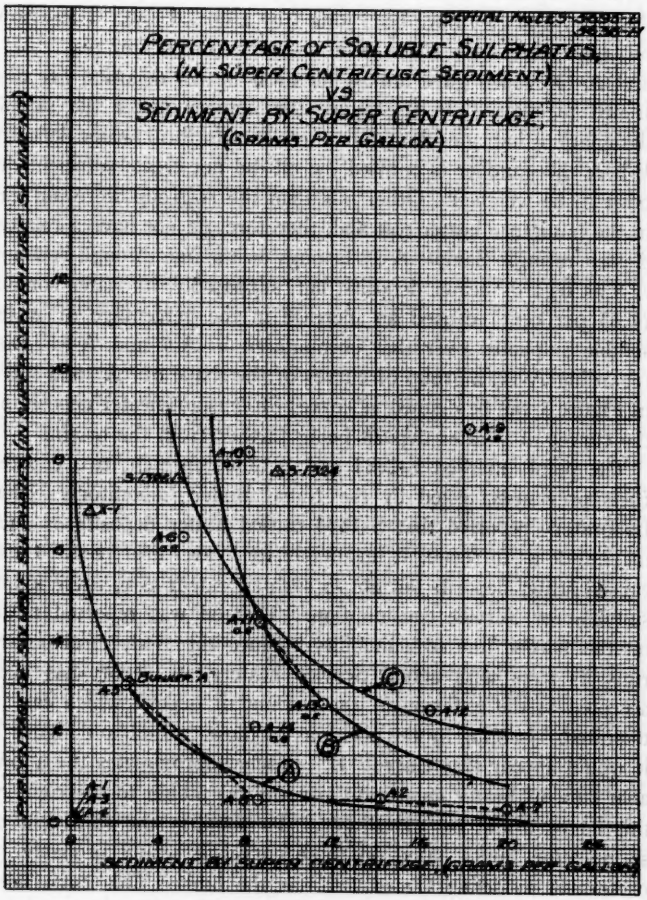
PERCENTAGE OF SOLUBLE SULPHATES
(IN SUPER CENTRIFUGE SEDIMENT)
VS
SEDIMENT BY SUPER CENTRIFUGE
(GRAMS PER GALLON)
PERCENTAGE OF SOLUBLE SULPHATES (IN SUPER CENTRIFUGE SEDIMENT)
SEDIMENT BY SUPER CENTRIFUGE (GRAMS PER GALLON)

FIGURE 1.

Early in the investigation it became apparent that none of the standard tests applied to fuel oils would give any indication of their performance in fuel oil heaters. The new test methods which were developed in the search for the desired criterion of this performance threw light on some other important characteristics of fuel oil behavior under Service conditions. The results of the Pressure Heater Test show that deposits which form in storage tanks are not controlled by the same factors as heater deposits. In this test a one-gallon sample of each oil was subjected to a temperature of 450 degrees F. for seven hours. Before and after the test a sediment determination was made on a small sample removed from the top of the oil. The change in percentage sediment in the top stratum of the oil in the heater was taken as the criterion of the tendency of the oil to deposit its sediment in storage. The sediment determination was made by a method devised at this Station especially for measuring the sediment in cracked fuel oils (see footnote to Table 4). This Revised Method for Determining Sediment in Fuel Oils was found to bear a remarkably uniform relation to the Super Centrifuge Test as long as the percentage of asphalts in the oil did not exceed 0.64 per cent. Samples A-3, A-4, A-12, A-13, and A-14 all exceeded this limit considerably and gave much higher sediment readings by the Revised Method than the Super Centrifuge Test gave them credit for. The asphalts were determined by the method described in the footnotes to Table 4. Figure 2 shows the correlation between the Revised Method and the Super Centrifuge Test. The sediment values obtained in these two test methods are tabulated in Table 4.

The existence of this correlation between the Revised Method and the Super Centrifuge Test makes it possible to use the Pressure Heater Test results to predict reactions to storage conditions. In Figure 3 are plotted the percentage change in sediment during the Pressure Heater Test versus Total Sediment by Super Centrifuge. The general indications are that the greater the total sediment in the oil the greater is the tendency to deposit that sediment in storage tanks. It, therefore, appears that a limit must be placed on total sediment by super centrifuge in order to obviate storage tank deposits, or to limit them to reasonable proportions. Tests under

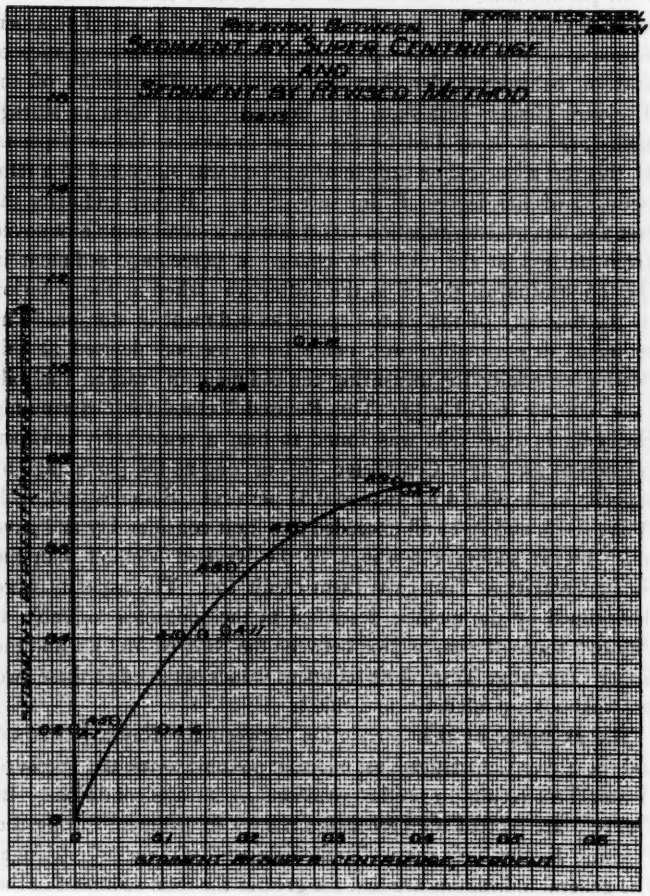

FIGURE 2.

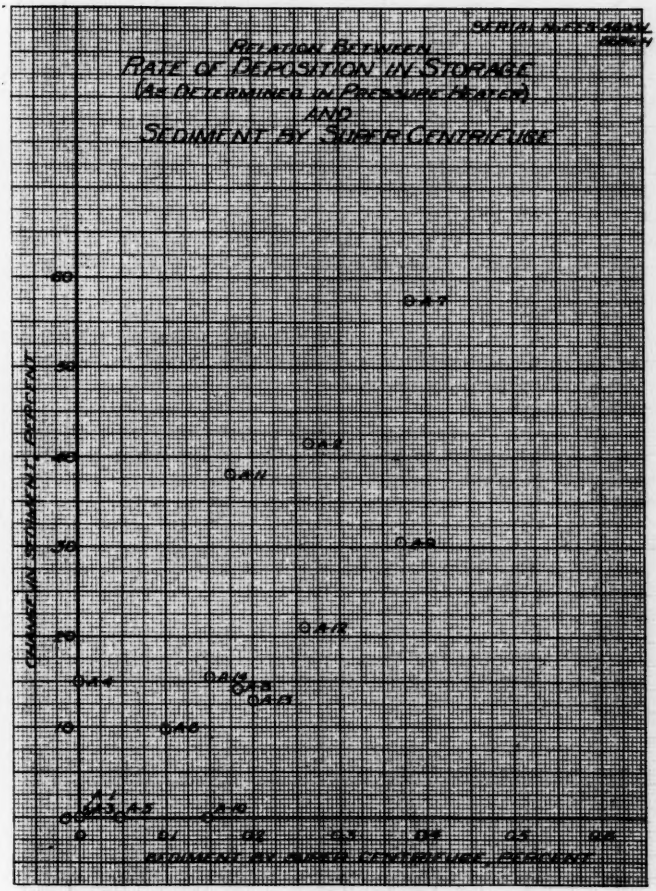
Relation Between
Rate of Deposition in Storage
(As Determined in Pressure Heater)
and
Sediment by Super Centrifuge
Sediment by Super Centrifuge, Percent
Rate of Deposition in Storage, Percent
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.21
0.22
0.23
0.24
0.25
0.26

FIGURE 3.

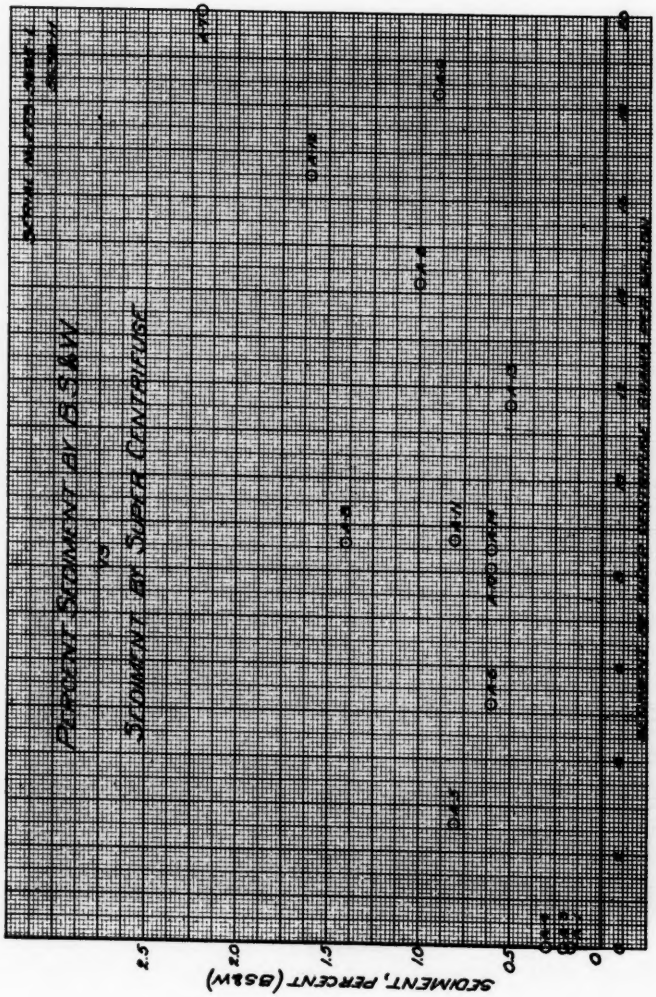
PERCENT SEDIMENT BY B.S.&W.
SEDIMENT BY SUPER CENTRIFUGE
SEDIMENT, PERCENT (B.S.&W.)
2.5
2.0
1.5
1.0
0.5
0

FIGURE 4.

FIGURE 4.

TABLE I

Class of oil - Bunker	"A"	"B"	"C"	"C"	"B"	"B"	"B"	"C"	"B"	"B"	"B"	"B"	"C"	"B"
Sample number	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14
Specific gravity at 60/60 deg.F.	1.010	0.986	1.020	1.017	0.990	0.981	0.987	0.965	1.008	0.984	0.963	1.019	1.003	0.990
A.P.I. degrees	8.59	12.01	7.20	7.60	11.43	12.74	11.86	15.13	8.87	12.30	15.44	7.36	9.57	11.43
Flash point, closed up, deg.F.	210	210	160	210	275	285	200	235	220	150	205	250	190	190
Pour point, deg.F.	-5	15	25	25	10	35	30	40	0	10	10	25	30	0
Viscosity, Saybolt Furol, at 77° F.	86	774	1130	1447	646	699	390	1601	219	511	132	770	1558	345
122 "	21	77	113	126	80	78	53	135	37	65	28	78	141	54
180 "	11	19	24	23	20	20	16	28	14	17	13	18	25	16
210 "	10	15	16	16	15	15	13	18	11	13	11	14	17	13
Neutralization number	0.11	0.08	0.14	0.14	0.11	0.11	0.08	0.06	0.11	0.09	0.12	0.12	0.06	0.09
Total sulphur, per cent	0.32	0.77	1.04	1.20	1.76	1.21	1.75	1.25	0.39	1.51	1.25	0.79	1.26	1.28
Water and sediment (ASTM)*, per cent	0.17	1.00	0.20	0.30	0.80	0.60	2.20	1.40	0.90	0.60	0.80	1.60	0.50	0.60
Water (ASTM)#, per cent	Trace	Trace	0.10	0.10	0.05	0.12	0.30	0.15	None	Trace	None	0.55	None	None
Carbon residue, per cent	9.00	10.68	19.34	18.98	12.18	10.70	12.18	11.56	10.52	11.81	9.42	15.13	15.51	13.49
Nature of carbon residue	Loose and flaky					Loose and flaky				Loose and flaky				
Ash, per cent	0.005	0.04	0.10	0.12	0.02	0.005	0.01	0.02	0.02	0.03	0.03	0.03	0.05	0.05
Sediment, % by weight (revised method)	0.20	0.65	2.48	3.30	0.22	0.20	0.73	0.56	0.75	0.41	0.42	1.06	1.56	0.96
Gross BTU's per lb. by calorimeter	18182	18353	18106	17816	18354	18154	18307	18563	18115	18190	18501	17912	17972	18207
Ultimate analysis:														
Carbon, per cent	89.98	87.13	85.95	86.28	85.65	86.75	86.32	86.85	88.58	87.65	86.35	89.56	87.52	86.47
Hydrogen, "	9.33	10.71	9.51	9.93	10.19	10.18	10.18	11.00	9.85	10.18	10.73	9.34	10.24	10.52
Sulphur, "	0.32	0.77	1.04	1.20	1.76	1.21	1.75	1.25	0.39	1.51	1.25	0.79	1.26	1.28
Nitrogen & Oxygen, per cent	0.37	1.39	3.50	2.69	2.40	1.86	1.75	0.90	1.18	0.66	1.67	0.31	0.98	1.73

* Method D96-24.

\# Method D95-27.

TABLE 2

Serial No. ~~3695-N~~ 3696-H

RESULTS OF CHEMICAL ANALYSES OF FUEL OIL HEATER DEPOSITS

Sample from U.S.S.	Heater No.	Moisture	Oil	Asphaltic Matter	Free Carbon	Sodium Chloride	Sodium Sulphate	Silica	Iron Oxide	Calcium Sulphate	Magnesium Sulphate	Magnesium Oxide	Calcium Oxide	Copper Oxide	Trisodium phosphate	Reaction	Description of Deposit
		Per cent															
CROWNINSHIELD		11.84	64.93	8.40	12.68	0.84	0.24	0.04	0.30	0.37	0.36					Neutral	
TRACY		45.09	38.59	4.91	5.00	1.96	0.47	0.20	0.90	0.75		0.13				•	
BUCHANAN		40.20	38.55	7.40	9.25	2.16	0.24	0.30	1.55	0.35						•	
SARATOGA		8.90	18.75	6.30	59.64	1.80	0.55	0.13	2.25	1.68		Trace				•	Carbonaceous powder
ALTAIR		14.90	42.80	16.05	22.40	1.05	0.23	0.20	1.63	0.74		•				•	Gritty semi-paste
SALINAS		8.03	33.05	16.08	39.77	0.20	0.18	0.25	1.30	1.14		•				•	Carbon. semi-powder
DORSEY		63.95	22.30	0.75	3.00	6.69	0.83	0.23	2.25			•	Trace			•	Semi-paste
MARBLEHEAD		45.49	29.44	3.73	13.77	0.16	0.11	0.40	6.90			•	•			•	Gritty semi-paste
YARNALL (143)		25.50	52.40	14.78	5.68	1.23	0.35									•	Oily liquid
HERBERT		8.34	22.50	21.90	43.97	1.09	0.33	0.15	0.55	1.17		•				•	Gritty semi-paste
	1	9.45	36.10	9.60	38.73	2.10	0.25	0.45	2.94			0.18	0.20			•	Gritty paste
	2	29.00	34.60	10.30	18.55	3.60	0.30	0.33	3.05			0.07	0.20			•	Gritty semi-paste
RAMSAY (124)	3	8.80	32.55	26.25	27.20	3.52	0.34	0.20	0.85			0.14	0.15			•	Gritty paste
	4	9.40	27.00	25.30	34.80	2.21	0.35	0.20	0.60			0.14	Trace			•	Gritty paste
	1	7.06	18.60	14.60	54.20	1.65		0.25	2.10		1.24		•			•	Carbonaceous powder
AYOCET (AM19)	2	17.18	23.60	9.65	45.10	1.29		0.10	1.80		1.28		•			Alk.	Carbon. semi-powder
CALIFORNIA		56.20	34.05	3.05	6.38	0.30										•	Oily liquid
CHICAGO		14.90	72.47	1.80	3.15	0.70	0.10	0.60	2.40	3.88		Trace				•	Oily liquid
	*	14.92	25.30	15.35	27.00	0.50	Trace	0.30	9.20	6.24	0.91	0.28				•	Gritty semi-paste
BRAZOS	+	6.80	12.30	3.40	6.60	0.20	Trace	1.10	3.20	7.75		Trace		58.65		•	Semi-paste with particles of metal
McCORMICK		14.87	74.75	6.17	3.40	0.77	0.18		0.16							•	Oily semi-paste
BULMER	2 Head	63.80	25.86	1.18	1.29	6.61	0.81		0.45							•	Paste
	2 Return	6.61	87.31	5.19	0.76	0.13										•	Oily liquid
NEW YORK	1A2	9.59	14.99	6.35	44.90	2.48	0.62	1.29	17.92	1.09		0.77				•	Carbonaceous powder
AARON WARD	1	3.91	92.32	2.25	1.33	0.19										•	Oily liquid
	1 ♯	16.30	75.11	3.91	4.68											•	Oily liquid
LONG	2 ♯	37.50	58.62	1.88	0.45										1.55	•	Oily liquid
	1	9.10	85.01	3.61	1.75	0.53										•	Oily liquid
ROPER	2	9.62	66.93	3.74	13.39	1.86		0.44	2.54	0.92		0.36				•	Gritty semi-paste

* Sample from heater coils ♯ Before boiling

\+ Sample from manifold discharge side of heater ♯ After boiling

Table 3.

Analyses of Super Centrifuge Sediment.

Sample No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14
Sediment at 250° F.	0	14.2	0	0	2.6	5.2	20.0	8.6	18.3	8.1	8.7	16.5	11.6	8.5
Analysis of Sediment.														
Moisture, per cent.		1.95			1.60	2.40	2.75	1.00	1.92	4.60	6.10	3.40	3.00	3.45
Oil , per cent.		29.10			29.25	25.40	26.88	22.15	20.43	27.00	20.10	35.92	31.00	29.00
Asphaltic Matter, %		22.30			24.15	21.43	22.10	28.85	23.05	26.52	30.55	22.32	16.40	14.24
Sodium Chloride, %		6.55			5.90	3.60	0.84	3.58	0.33	2.24	10.94	3.50	19.59	20.80
Sodium Sulphate, %		0.35*			2.10*	4.55*	0.26*	0.37*	6.83*	5.62*	3.29*	1.52*	—	—
Calcium Sulphate, %		1.22			1.92	1.92	0.37	—	0.73	0.85	0.65	—	1.73*	1.43*
Magnesium Sulphate, %		0.66			0.52	—	—	—	0.66	0.66	0.42	—	—	—
Free Carbon, %		35.77			29.40	36.60	45.17	38.80	44.65	31.15	26.15	30.08	24.60	26.22
Silica, %		—			0.31	—	0.10	1.35	—	0.11	0.40	1.10	0.75	0.70
Iron Oxide, %		2.10			4.85	3.70	1.20	3.35	1.40	1.25	1.40	1.95	1.68	3.00
Calcium Oxide, %		—			—	—	0.15	0.25	—	—	—	Trace	1.00	0.91
Magnesium Oxide, %		—			—	0.40	0.18	0.30	—	—	—	0.21	0.25	0.25
Reaction.		Alk.			Neut.	Alk.	Neutral							

* Water-Soluble Sulphates.

Service conditions of storage were not carried out so it is not possible to specify the desirable sediment limit to prevent tank deposits.

The B. S. & W. Test was found to be a poor criterion of the actual sediment in the oil. The relation between this test and the super centrifuge results is shown in Figure 4. Correlation is only very general. It will also be noted that the oils whose sediment showed high percentages of soluble sulphates gave lower B. S. & W. readings than oils of the same sediment content with low percentages of sulphates.

Such were some of the more interesting relations which were developed as a result of obtaining from the oil the undiluted and unadulterated sediment. The Super Centrifuge Test was a veritable "Open Sesame" to the entire investigation conducted at this Station.

TABLE 4

SAMPLE No.	SUPER CENTRIFUGE SEDIMENT. (GMS/GAL).	RELATIVE TENDENCY TO FORM HEATER DEPOSIT.	PERCENTAGE OF SOLUBLE SULPHATES. (UNCORRECTED)	PERCENTAGE ASPHALTS BY METHOD. (a) (c)	PERCENT SEDIMENT BY REVISED METHOD. (b).	SUPER CENTRIFUGE SEDIMENT % BY WEIGHT.	% CHANGE IN SEDIMENT IN PRESSURE HEATER TEST.	PERCENTAGE BS & W	DESCRIPTION OF SUPER CENTRIFUGE SEDIMENT.	REMARKS.
A-1	—	0	—	0.05	0.20	0	0	0.17	—	
A-2	14.2	*	0.508	0.26	0.65	0.26	-41.5	1.00	Dry	
A-3	—	0	—	1.58	2.48	0	+ 0.8	0.20	—	
A-4	—	0	—	1.29	3.30	0	- 15.5	0.30	—	
A-5	2.6	*	3.035	0.25	0.22	0.05	- 9.1	0.80	Sticky	
A-6	5.2	0.2	6.300	0.42	0.20	0.10	- 10.0	0.60	"	
A-7	20.0	*	0.365	0.53	0.73	0.38	-57.5	2.20	Dry	
A-8	8.6	*	0.481	0.45	0.56	0.18	- 14.2	1.40	"	
A-9	18.3	1.9	8.790	0.27	0.75	0.37	-30.5	0.90	Sticky	
A-10	8.1	0.7	6.220	0.43	0.41	0.15	+ 12.2	0.60	"	
A-11	8.7	0.5	4.450	0.64	0.42	0.18	-37.5	0.80	"	
A-12	16.5	*	2.500	1.67	1.06	0.26	-21.0	1.60	Dry	0.55% water
A-13	11.6	0.5	2.620	2.97	1.56	0.20	- 13.0	0.50	Sticky	
A-14	8.5	0.6	2.120	1.79	0.96	0.15	- 15.5	0.60	"	

* Indicates very slight heater deposits.

$$\text{Supercentrifuge Sediment, \% by weight} = \frac{\text{Sediment by S.G.} \times [100-(\%\text{ moisture} + \%\text{ oil})]}{5785 - \text{Sp. Gr. of oil}}$$

$$\%\text{ Soluble Sulphates (Corrected)} = \frac{\%\text{ Soluble Sulphates in Sediment}}{100-(\%\text{ moisture} + \%\text{ oil})}$$

(A) METHOD (2)

Hot Pressure or Vacuum Filtration Using "Filter Aid" on the Principle of the Kelly Filter.

In refineries the Kelly filter is used to remove finely divided carbon insoluble compounds of an asphaltic nature from fuel oils. The method modified at the Engineering Experiment Station, using vacuum filtration the oil heated to 250 deg.F. and keeping up the temperature during the ess of filtration by means of a hot water funnel.

ratus

One 100 c.c. evaporate, one Gooch crucible of 30 c.c. capacity with tion flask, and one hot water funnel.

ents

ASTM precipitation naphtha, benzol, and Hyflo Supercell.

edure

Approximately 20 grams of the oil to be tested are weighed into a porate. The oil is heated to 250 deg.F. and filtered immediately, g suction, into a weighed Gooch crucible having an asbestos pad and gram of ignited Hyflo Supercell. The filtered oil is reserved and saved further determination. The adhering oil in the evaporate is washed o the Gooch with ASTM precipitation naphtha and the washing is maintained il the wash liquid is clear. The Gooch is dried at 110 deg.C. for one- r hour, cooled, and weighed.

$$\frac{\text{Weight of residue} \times 100}{\text{Weight of sample}} = \text{Per cent of asphaltic matter and matter insoluble in precipitation naphtha.}$$

The Gooch is again connected with a suction flask and washed with benzol il the wash liquid is clear. It is then dried to constant weight, cooled weighed.

$$\frac{\text{Weight of residue} \times 100}{\text{Weight of sample}} = \text{Per cent of matter insoluble in benzol.}$$

The asphaltic matter is the difference of the percentages in the above determinations.

A determination of the benzol insoluble is made on the filtered sample using the revised method of determining sediment in fuel oil (Plate 5).

(4) REVISED METHOD of Determining Sediment in Fuel Oil.

Weigh five grams of the fuel oil into a 250 c.c. Erlenmeyer flask. Add 200 c.cs. of 90 per cent benzol and mix thoroughly by shaking. Allow a sample to stand for 24 hours at room temperature. Prepare a Gooch crucible with an asbestos pad about 1/2-inch thick. The asbestos pad is deposited in the bottom of the crucible by suction from a mixture of acid-treated asbestos fibre in distilled water. The pad is washed with alcohol and the prepared crucible dried to constant weight at 110 deg.C.

Filter the sample of fuel oil in 90 per cent benzol through the prepared crucible by means of suction, wash thoroughly with 90 per cent benzol and dry the crucible and its contents to constant weight at 110 deg.C.

The per cent of sediment in the oil is the net increase in weight of the prepared crucible divided by 5 and multiplied by 100.

INVESTIGATION OF CRACKED FUEL OILS AT THE NAVAL BOILER LABORATORY.

By Lieutenant Commander R. C. Brierly, U. S. N. R.

Fuel oils now being produced by the principal petroleum refining companies are largely blends or straight residues from cracking stills. Some of these fuel oils, because of inherent physical or chemical instability, states of aggregation of the carbon or other compounds contained in them, molecular composition of the constituents, presence of impurities, or other reasons, may be unacceptable for Naval use.

Commercial desirability is not a criterion of Naval acceptability. Difficulties which may be tolerated in the Merchant Service or in the activities of many shore plants cannot be permitted to occur in Naval operation. Reliability and maneuverability in the strictest sense are imperative; economy of operation is practically of equal importance for the reason that the designed power of Naval vessels must be obtainable with the fuel in use at all times. Serious consequences may ensue from lapse in commercial steam production; disasters perhaps little short of catastrophic may follow such an incident in wartime Naval boiler operation.

An investigation, still in progress, was begun at the Naval Boiler Laboratory to institute lines of demarcation between acceptable and unacceptable fuel oils. It contemplates revision of fuel oil specifications to allow purchase of cracked and/or high carbon fuel oils, but to disbar fuel oils possessing any characteristics which may jeopardize facility of operation or lower efficiency to an extent disproportionate to price differences.

Establishment of accurate differentiation requires operation with, and study of, a large number of cracked and residual oils having the greatest possible " spread " of the varied characteristics encountered in such fuels. All possible phases of storage, handling, pumping, heating, and combustion should be considered in this problem.

Twenty cracked residues, or blends of cracked residues, together with bunker fuel oils selected as "base" oils, have been used thus far in this investigation. These twenty fuel oils, which may be characterized as "cracked," have been obtained from widely scattered refineries throughout the United States; they represent residues and blends from practically every type of cracking still now in general use. Alphabetical designations have been employed to identify these oils; letters A to R inclusive and Y and Z have been used. These oils have been kept in storage for the longest possible time compatible with the early completion of this investigation. After such periods of storage, they have been subjected to pumping, heating, and atomizing runs, then finally burned under the boilers of this Laboratory.

STORAGE.

Oils received have been stored in 2000-gallon compartments constructed specially for this test. Each compartment has been cleaned by hand with kerosene and cloth and carefully dried prior to placing any oil in it.

PUMPING.

The pumping runs were conducted at various temperatures and viscosities by taking suction on the individual oil compartments by means of a Kinney rotating plunger pump, which delivered the oil to the Laboratory's weighing and constant level fuel oil tanks; from the latter it was again pumped to empty compartments by way of the fuel oil heaters. The purpose of this phase of the investigation was to ascertain the viscosities and temperatures at which viscosity itself ceased to be a predominant factor in pumping.

HEATERS.

A Schutte Koerting type 61 fuel oil heater was used to obtain data concerning deposition of carbonaceous material at reduced viscosities and elevated temperatures. The oil passed through the cylindrical body in this heater, while the steam passed through the tubes. The velocities of the fuel oils in the heater were varied

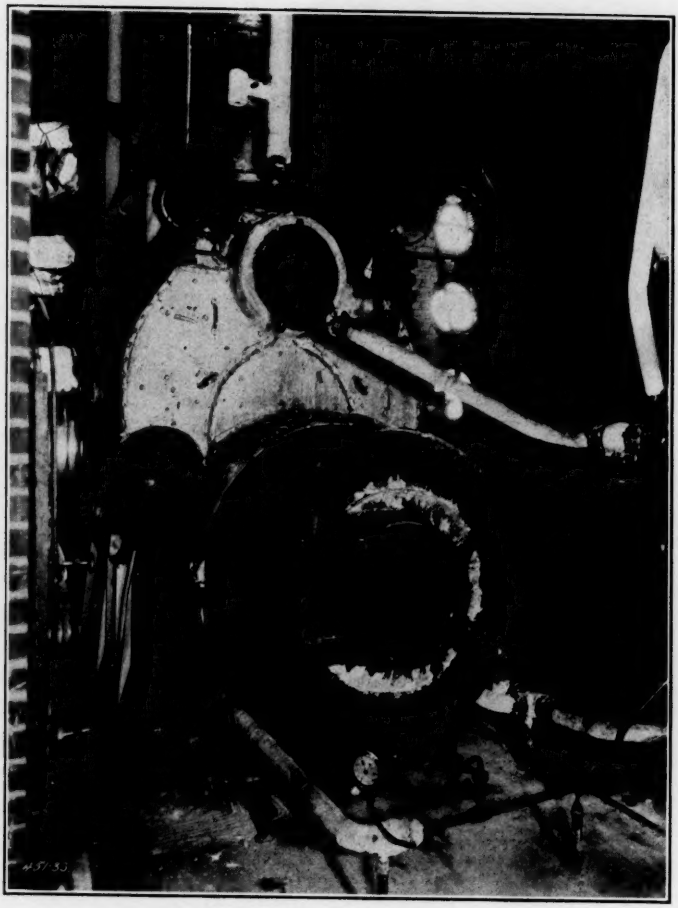

PLATE 1.

between one and two feet per second. Fuel oil pressures were varied between 200 and 300 pounds per square inch, while temperatures were those necessary for viscosities of approximately 150, 100 and 75 seconds Saybolt Universal.

BOILERS.

Evaporative efficiency runs were made on a 500-square foot launch boiler with a specially designed cylindrical furnace. The boiler was fired with one conical register and a small atomizer. The reasons for using this boiler were to obtain as much information as possible with the smallest expenditure of fuel oil and to note whether plugging occurred in the small passages of the atomizer. The design of atomizer used represented in miniature practically all atomizers used in present construction. The principal particulars of the launch boiler were:

Working Pressure, pounds	250
Boiler Water Heating Surface, square feet	500
Superheating Surface, square feet	0
Furnace Volume, cubic feet	78.7
Outside Diameter of Tubes, inches	1.0
Thickness of Tube Walls, inches	0.095
Number of Tubes	636
Area of Rear Wall, square feet	13.7
Side Walls, square feet	24.5
Under Tubes, square feet	42.8
Front Wall, square feet	8.7
Area of Refractory Surface, square feet	89.7
Radiant Heat Absorption Surface (Tent Area), square feet	20.2
Ratio of Absorption Surface to Refractory Surface (Fraction Cold)	0.225

The furnace brickwork was 4½ inches thick, backed with ½ inch of uncalcined diatomaceous earth insulating blocks.

The boiler itself was built at the Norfolk Navy Yard in 1917.

The specially designed furnace and brickwork erected for this test was installed in June, 1933. The appearance of the boiler is shown in Plate 1.

During operation of the launch boiler a small feed pump, fuel oil pump, feed heater, and fuel oil heater, integral with the boiler's own system, were used instead of the Laboratory's main auxiliaries.

Runs were made with each cracked fuel oil and with the bunker base oils at a constant pressure of 275 pounds per square inch on the manifold before the atomizer. The viscosity was altered between runs over the range between approximately 75 seconds and 500 seconds Saybolt Universal for each oil. The principal reasons for making runs at four viscosities with each cracked oil were:

1. To ascertain whether the optimum viscosity was 150 S.S.U. as with normal bunker oils.

2. To check by evaporative efficiency whether excessive deposition of carbonaceous material had occurred in the fuel oil heater, or on the atomizer tip.

3. To find the optimum viscosity for operation without excessive loss of carbonaceous material with the stack gases.

4. To fix the influence of cracked fuel oils on furnace brickwork.

Changes in viscosities caused the firing rates employed on the launch boiler to range from 0.45 to 0.6 pounds per square foot G.H.S. per hour, because of the varying capacity of the atomizer. During all boiler operation observations were taken of flame conditions, flame temperatures, flue gas, and smoke conditions. Samples of slag and smoke particles were taken. These samples were obtained from the stack by use of an aspirator and vacuum cleaner bag, in such a way that the amounts of solids in the flue gases leaving the boiler could be checked closely.

Other runs were made on the Laboratory's 6170-square foot Dyson express boiler at pressures ranging from 200 to 500 pounds per square inch. This operation was conducted in order to ascertain whether increased pressure acted as a substitute for decreased viscosity. Multiple burner operation with residual oils was conducted for check purposes on some of the Laboratory's larger express boilers.

Analyses of the fuel oils in question were made continually throughout the investigation.

PUMPING RESULTS.

The pumping data secured have established that for Navy installations viscosity itself diminishes rapidly as a predominant factor at viscosities in the order of 4000 S.S.U., 420 S.S.F., and practically ceases to be such a factor at 3000 S.S.U., 330 S.S.F. Thus the old 100-degree Engler figure established many years ago was not far from correct.

The temperatures required for 4000 S.S.U. on the cracked fuel oils thus far tested averaged 79 degrees F. and those for 3000 S.S.U., 85 degrees F. The highest temperature necessary for pumping at 3000 S.S.U. for these cracked fuel oils was 110 degrees F.; the lowest 43 degrees F.

HEATER RESULTS.

Carbonaceous deposits in the fuel oil heater were obtained with four out of the twenty cracked fuel oils run. One of these tended to cause deposition over a wide range of temperatures which would not allow reduction of viscosity to 150 S.S.U. The second and third of these four oils threw down carbon at temperatures closely corresponding to 150 S.S.U. but did not cause deposits at temperatures corresponding to 225 S.S.U. The fourth of these four oils caused carbon deposition at temperatures corresponding to about 100 S.S.U. While this oil would cause little difficulty for normal commercial operation, it would be unacceptable for Naval use because of probable fouling of the heater during maneuvering.

The average preheat required for reducing these cracked fuel oils to viscosities of 150 S.S.U was 178 degrees. The highest heating temperature required for this viscosity with any of these oils was 213 degrees F.; the lowest 131 degrees F.

Increase in operating viscosity from 150 S.S.U. to 225 S.S.U. would allow a reduction of approximately 18 degrees F. in the required preheat temperature with practically all the cracked fuel oils tested; further increase in viscosity from 225 S.S.U. to 300 S.S.U. would allow an additional reduction of 11 degrees F. in preheat; thus, the total reduction in preheat for viscosity increase from 150 to 300 S.S.U. would be in order of 29 degrees F. In the case of cracked fuel oils which tend to cause carbon deposition in the fuel oil heaters at viscosities around 150 S.S.U., increase

in operating viscosity to 300 S.S.U. might preclude excessive fouling. Such an increase in viscosity is not desirable, however, from other operating standpoints.

Increase in the pressure of fuel oil to the atomizers from 300 pounds per square inch gage to 500 pounds per square inch gage will compensate for increase in viscosities up to about 350 seconds Saybolt Universal, but the advisability of such a pressure and power increase for the relatively small lowering of preheating temperature is debatable.

INFLUENCE OF VISCOSITY ON ATOMIZER CAPACITY.

It may be said, in general, that increase in viscosity by decreasing the fuel oil preheat increases the capacity of a given atomizer in pounds atomized at a constant pressure. The lower the temperature, the greater the weight for a given volume. Weight capacity does not increase directly with increasing viscosity, however, because increasing friction in the slots and whirling chambers of sprayer plates and, at low viscosities, partial gasification, are qualifying factors.

DEPOSITS ON ATOMIZERS.

Deposition of carbonaceous material on the faces of the atomizers occurred during operation with about half the cracked fuel oils used during the present series. The speed of deposition with all but one oil, wherewith deposition occurred, increased with increasing viscosity by reduction of preheat up to about 300 to 350 S.S.U. but again lessened slightly at viscosities above that figure. The increased rapidity of deposition is considered due to decreased speed of combustion with increased viscosity, which causes increasing coarseness of atomization. There was little reduction in efficiencies through the occurrence of these carbon deposits, but on changes of viscosity from high to low, widening of the spray angle through such viscosity decrease caused striking against the conical carbon deposits, making cleaning imperative if efficiencies were to be maintained. All the cracked fuel oils used and the base oils as well showed increasing coarseness of atomization with increasing viscosity. This was apparent in the size of the sparks

from the flame tails and shape of the flame and the necessity for increasing air pressures, which, with all other conditions constant, are a function of particle size as well as firing rate. The angles of spray tend to decrease with increasing viscosity and with some cracked fuel oils the combustion speed is such that this reduction of angle diminishes the tendency to coke the sprayer plates at viscosities in the order of 450 S.S.U.

The flames did not become noticeably narrower nor did they change markedly in appearance over the range of viscosities from 150 S.S.U. to nearly 300 S.S.U. At almost exactly 300 S.S.U., however, the character of the atomization changes; with some oils it ceases to occur immediately beyond the sprayer plate orifice, causing an umbrella or sheet of oil to extend into the furnace for a distance of three or four inches beyond the atomizer end. This area is normally brown against the flame body and constitutes an area of little if any combustion. Fireroom air pressures had to be considerably advanced when such changes in flame appearance occurred. With other fuel oils the flames simply narrow still further, coarseness of atomization increases, but combustion speed seems to be maintained when excess air and fireroom air pressures are increased. In other words, the increased excess air necessitated by the narrower flame and coarser atomization is sufficient to overcome the slower speed of combustion and allow fair operation in flame conditions to be obtained. Logically, coarseness of atomization is an adverse factor, but narrowness of the spray angle may be helpful by producing greater flame concentration. It is interesting to note that on several merchant ships the difficulties arising from the combustion of cracked fuel oils have been considerably alleviated through the use of narrow angled sprayer plates.

SLAG.

Samples of slag taken from a slag trough at the bottom of the furnace were thoroughly examined after operation with each fuel oil. The amounts obtained from combustion of these cracked fuel oils were, in general, no greater than those from firing normal bunker oils. The principal slag forming elements present were iron basic fluxes and low melting point clays.

SMOKE SAMPLES.

The data obtained on carbonaceous solids leaving the boiler indicate that:

(*a*) The use of cracked residues was accompanied by loss of carbonaceous materials in the stack gases. The amounts of these materials are very much greater than those produced by non-cracked fuel oils of any type yet tested.

(*b*) This loss was to a large extent one of carbon, although hydro-carbons and ash also exist in the materials. In one case clay particles formed the major constituent of the so called stack solids.

(*c*) The difference in efficiencies between cracked and uncracked fuel oils was due largely to hydrocarbon losses. These losses consist of gaseous hydrocarbons, together with solid hydrocarbons and carbon as with other fuel oils, except that the percentage of carbon and asphaltic material forms a very much higher percentage of the hydrocarbon loss.

(*d*) The firing of cracked residual oils is to a large extent analogous to the firing of so called "colloidal" fuel (coal and oil mixtures) or to a lesser extent pulverized coal itself. With either colloidal fuel or pulverized coal, theoretical efficiencies, even after deductions for all ordinary losses, are high; it is generally the hydrocarbon losses, often amounting to 10 per cent, which reduce furnace and burner efficiencies and therefore overall efficiencies.

(*e*) Hot furnaces are very important in the combustion of colloidal fuel or pulverized coal. The hotter the furnace, the more rapid the combustion of the complex molecules. This is true of cracked fuel oils as well as colloidal fuel oil and pulverized coal.

(*f*) Furnaces should not only be hot (in general, the lower their fraction cold the better) but their size also must be considered. The distances from burner centers to the side walls, floor, and tubes, while important in any fuel oil burning installation become increasingly so in the case of cracked fuel oils. For here, with slower burning particles, the time factor in combustion is greater, and increasing care must be exercised to avoid chilling of partially burned particles.

(*g*) The principal factors in increasing combustion speed of any fuel are the furnace temperature, the design of burner, and

the fineness of the particles atomized. These must be given increasing attention in the burning of cracked fuel oils.

(*h*) It is probable that, particularly with the vessels having older types of fuel oil burning installations, deposition of carbonaceous materials on the decks, in the banks and stacks of the boiler will occur to a large degree. There will be difficulty in preventing the ejection of large quantities of carbonaceous materials from the stacks; the truly smokeless condition will be difficult to obtain, but the smoke will be different from that ordinarily obtained with non-cracked fuel oils. Instead of being composed of a relatively large quantity of finely divided carbonaceous particles, it will consist of a relatively smaller number of large pumice—or—slaglike—spiny particles of carbon and asphalt or globular "sinospheres."

(*i*) High percentages of stack solids usually were emitted at the high operating viscosities.

(*j*) The amount of debris from the stacks of a cruiser during an eight-hour run at full power with cracked fuel oil, at 150 S.S.U. operating viscosity, might be 600 to 700 pounds total; it would be more at higher viscosities.

Carbonaceous or asphaltic particles in the stack gases occur to a greater or less extent with all cracked fuel oil. These particles do not constitute smoke but cause accumulations of pumicelike debris on the decks, superstructures, and all exposed parts of the vessel burning such oil. They will also tend to deposit in the tube banks, uptakes, and the drums of the boilers using these oils and necessitate more frequent use of soot blowers.

The presence of this material is due to the "popped" carbon compounds in the cracked fuel oils. The cracking process to which the oils have been subjected establishes carbon compounds, or forms of carbon itself, which do not readily unite with the oxygen of the air. It is probable that remedies may be devised to reduce the amounts of these stack solids, but their complete eradication at this time is considered virtually impossible.

Something somewhat resembling this deposit can be obtained when burning non-cracked fuel oils at viscosities higher than 300 S.S.U.; at viscosities below this, however, no such solids occur in normal operation. The material emitted from the stack during the

combustion of non-cracked fuel oils, however, is not the same as that accompanying the use of cracked fuel oils.

The stack solids from cracked fuel oil are not ash. They are carbonaceous material with some hydrogen and ash accompanying it. These losses are at their minimum when the cracked fuel oils are being burned at 150 S.S.U. viscosity.

Operation and efficiency data obtained with the cracked fuel oils as compared with the non-cracked base oils are as follows:

(*a*) *Fireroom Air Pressures:* Fireroom air pressure requirements are not greatly dissimilar; eight out of the twenty cracked fuel oils run required somewhat higher fireroom air pressures than non-cracked fuel oils; the remainder required approximately the same or less.

(*b*) The excess air used was in the order of 5 per cent higher with cracked fuels than with Bunker A at viscosities below 300 S.S.U.; it was somewhat less at viscosities above that figure.

(*c*) Carbon dioxide percentages, in general, were higher than with Bunker A. The percentages of carbon dioxide obtainable with any given fuel are functions of the amount of carbon present in the oil, as well as the dilution of the gases due to hydrogen, sulphur, and nitrogen products. The CO_2 percentages obtainable with cracked fuel oil are theoretically higher than with most normal fuel oils on account of the higher carbon content of the former.

Efficiencies, except in the case of the absorption surfaces, were less with cracked fuel oils than with non-cracked fuel oils. This is due to decreased furnace and burner efficiencies in the order of 1 to 2 per cent, which are in turn directly due to relatively high hydrocarbon losses.

Comparative results on the launch boiler are shown in Plates 2 and 3. The curves designated by letters are those obtained from operation with cracked fuel oils; B, C and G may be considered typical. The curves designated by the number S–1406 were secured with a typical Bunker "A" fuel oil.

A few of the most pertinent conclusions made to date are:

1. Provision should be made for heating the fuel oil in storage compartments to approximately 100 degrees F. even under sub-arctic conditions.

INFLUENCE OF CONSTANT PRESSURE VARIABLE VISCOSITY ON EFFICIENCIES AND HYDROCARBON LOSSES
(LAUNCH BOILER)

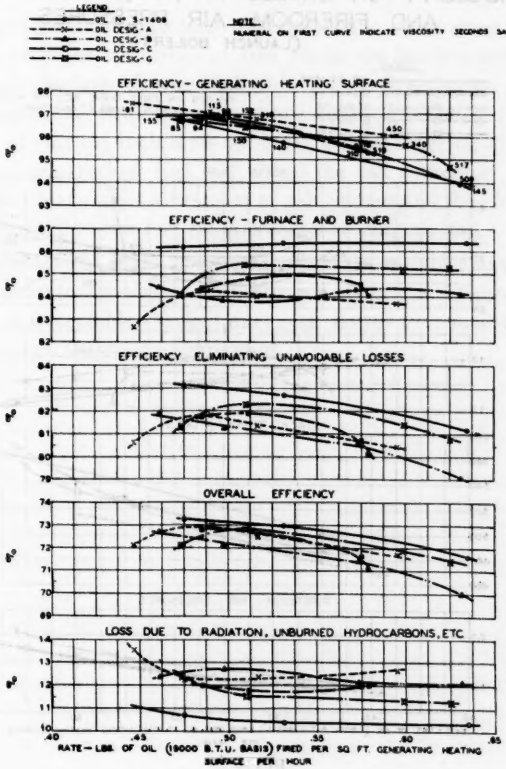
LEGEND
OIL N° S-1408
OIL DESIG-A
OIL DESIG-B
OIL DESIG-C
OIL DESIG-G
NOTE
NUMERAL ON FIRST CURVE INDICATE VISCOSITY SECONDS SAYBOLT UNIVER
EFFICIENCY - GENERATING HEATING SURFACE
EFFICIENCY - FURNACE AND BURNER
EFFICIENCY ELIMINATING UNAVOIDABLE LOSSES
OVERALL EFFICIENCY
LOSS DUE TO RADIATION, UNBURNED HYDROCARBONS, ETC
RATE — LBS. OF OIL (19000 B.T.U. BASIS) FIRED PER SQ. FT. GENERATING HEATING SURFACE PER HOUR

PLATE 2.

INFLUENCE OF CONSTANT PRESSURE VARIABLE VISCOSITY ON EXCESS AIR, CO_2, STACK TEMP. AND FIREROOM AIR PRESSURES.

(LAUNCH BOILER)

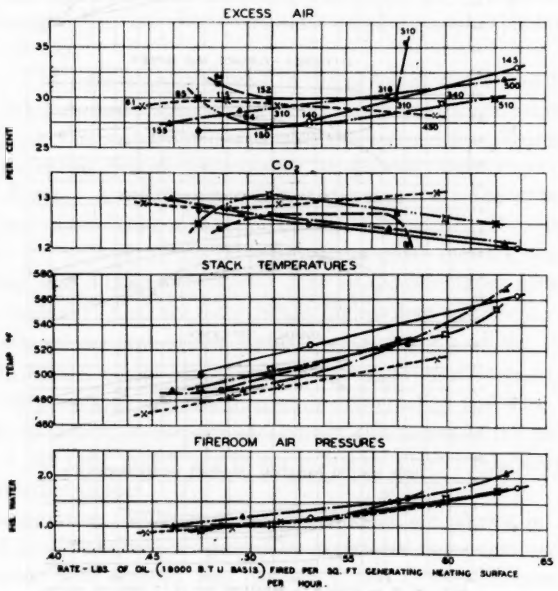

PLATE 3.

2. The optimum viscosity for fuel oil to the burners is 150 S.S.U. for cracked fuel oil as well as non-cracked fuel oil.

3. Excessive deposits of carbonaceous material in storage tanks, lines, strainers, atomizers, and particularly, as well as most seriously, in the fuel oil heaters, do occur with certain types of cracked fuel oil.

4. Losses with carbonaceous material in the stack gases are at their minima when viscosities of fuel oils to the burners are about 150 seconds Saybolt Universal, but furnace temperatures, burner arrangements and flame conditions are highly qualifying factors.

5. Use of cracked fuels does not cause greater slagging of brickwork than non-cracked fuel oils unless the ash content is abnormally high. Slagging is a function of ash content and the character of the ash whether the fuel oil is cracked or non-cracked.

The influences of many previously uncertain variables have been isolated; definite knowledge of the processes or causes producing definitely unacceptable cracked fuel oils, however, remains to be established by continued investigation.

THE NAVY'S TENTATIVE SPECIFICATIONS FOR FUEL OIL—FISCAL YEAR 1935.

By F. M. McGeary.*

The preparation of a specification for any material is the prerogative of the user and the purpose should always be to define a given material in technical terms that may be readily understood and applied by both the purchaser and the seller. Extraneous matter and generalities should be avoided. Technical requirements should be based upon knowledge of the use to which the material will be put and of the characteristics of a suitable supply of available materials. On this basis no specification should be so loose that all of the material produced will be satisfactory thereunder nor should it be so tight that the material can be produced by only a few isolated sources. In other words, a specification should require a quality of material most suitable for the purpose which can be readily obtained at a reasonable cost.

In Government purchasing where sealed bids are opened at a given time and award of contract is made to the low bidder agreeing to furnish material in accordance with the specifications of the schedule it is more necessary to have a definite requirement than in commercial purchasing where negotiation of contracts is the rule. The commercial purchaser is not bound by legal restrictions such as apply to Government purchasing, nor does he have to advertise his requirements. He can confine his negotiations to as few as one supplier if he so desires. Furthermore, after the order is placed and the material is delivered he can and frequently does reject it for unsatisfactory operation even though it may conform to a common understanding between the purchaser and the seller. The Government has no such recourse. If the material conforms to the specifications of the contract it remains Government property notwithstanding it may not show satisfactory results in operation.

* Engineer (Materials), Bureau of Engineering, Navy Department.

The Navy Department has always endeavored to prepare specifications for material to assure its satisfactory use under conditions peculiar to Naval vessels where operating conditions are generally different from those prevailing in any other service. Material which can be used in the regular marine service or in stationary power plants ashore is not always suitable for use on Naval vessels. On the other hand, material which can be used by the Navy is entirely suitable for regular marine service or in stationary power plants ashore. This condition is not always properly considered in the preparation of Government specifications.

The Navy Department has used fuel oil for more than 25 years. For the past 15 years it has been practically dependent upon fuel oil for the generation of steam in all combatant vessels. In general satisfactory operation has been obtained with fuel oil purchased under existing Governmental specifications. That this is so does not necessarily mean that these specifications are ample; instead it indicates that there has been an abundance of oil suitable for use as fuel under Naval conditions. That this conclusion is correct is shown by the fact that up until about four years ago it was possible to obtain a fuel oil with the fluidity and other characteristics of Bunker A under a Bunker C designation at Pacific port delivery points. This condition prevailed for at least ten years prior to 1930 and served to create a feeling of security that practically stopped all studies of fuel oil problems.

Since 1930 it has been evident that conditions pertaining to fuel oil supply were changing rapidly and in a direction that would probably prove disastrous to the Navy, unless suitable steps were taken. The reason for these changing conditions which are chiefly economic will be given in detail by others. As a result of a general survey of the fuel oil situation it became necessary to prepare a new specification to provide one compromise fuel oil to replace the three grades covered heretofore and known as Bunker A, Bunker B and Bunker C.

Of these three grades Bunker C has the greatest availability, Bunker B is still readily available, while Bunker A has practically disappeared. Bunker C with its present maximum viscosity of 300 seconds Saybolt Furol at 122 degrees F. is not suitable for

use in a large number of Naval vessels if fuel oil approaching the maximum viscosity limit should be delivered under contract. Pumps for Naval vessels are required to handle fuel oil having a viscosity of 700 seconds Saybolt Furol, while burners are required to operate with oil having a viscosity of not more than 150 seconds Saybolt Universal (approximately 15 seconds Saybolt Furol). If we assume that viscosity-temperature is a straight line function, a Bunker C oil of maximum viscosity will require a temperature of approximately 100 degrees F. for 700 seconds S.F. and a temperature of approximately 235 degrees F. for 150 seconds S.U. Both of these temperatures will necessitate more heating of the oil than is possible or desirable on a large number of vessels.

The fluidity of fuel oil which is measured by its viscosity is one of the important characteristics of fuel oil for naval use. In developing the present specification it was concluded that present facilities on a number of important units of the fleet demanded a fuel oil which would have a viscosity of 700 seconds S.F. at not higher than 80 degrees F. and which would give a viscosity of 150 seconds S.U. at not higher than 185 degrees F. to reduce heating to a minimum. Heretofore the conventional method of specifying viscosity has been to require a maximum viscosity at one temperature which for oil of this fluidity is 122 degrees F. This method is convenient from a laboratory standpoint but would not always assure a suitable viscosity at 80 degrees F. nor a temperature of below 185 degrees F. for 150 seconds S.U. This is due to the fact that the slope of the viscosity-temperature curve does not always follow the same angle. For this reason viscosity is specified in terms of workable fluidity at two points; a temperature of 77 degrees F. being substituted for 80 degrees F. because the former is a standard temperature for measuring viscosity. A viscosity of 750 seconds S.F. at 77 degrees F. will show about 700 seconds S.F. at 80 degrees F.

The flash point which is of importance from a safety standpoint has been left at "not less than 150 degrees F." A fire point of "not less than 220 degrees F." has been added to assure that the fire point is at least 35 degrees F. above the temperature to which the oil will be heated. It is further provided that if the flash

point of the oil is 175 degrees F. or higher, the fire point need not be determined nor reported. This provision assures a fire point above 220 degrees F. as there is usually a spread of 50 to 75 degrees between the flash and the fire point. Flash and fire points are made in a Pensky-Marten closed tester.

The total water content is limited to 1.0 per cent with a proviso that oil containing 2.0 per cent water will be accepted but a reduction of (1.25 times water in excess of 1.0 per cent) will be applied to the contract price.

The foregoing requirements, that is, viscosity, flash point, and water content are those characteristics which have determined the quality of fuel oil delivered up to now.

To these have been added three additional quality requirements, *i.e.* ash, heater fouling tendency, and stability in storage.

Ash has been placed at 0.12 per cent until such time as more information is available. It is known that ash is detrimental to the brick work in the boiler but it has not been definitely determined whether it is the quantity of ash or the character of the ash which has to be guarded against. For example, an ash content of 0.10 per cent which contains 80 per cent of salts may be and probably is more destructive to brick work than an ash content of 0.40 per cent which contains only 10 per cent of salts. It may eventually be necessary to limit both the total ash and the destructive salts.

The heater fouling tendency of fuel oil is specified in general terms only and the responsibility for unsatisfactory results in this respect placed upon the supplier. This may or may not be fair depending upon the point of view. The fact remains that during the past few years there has been more trouble in the fleet from heater fouling than occurred during the previous years. The equipment has not been changed, so we may assume that the character of the oil is responsible for the fouling tendency. At present it is not known what characteristic of the oil will accentuate heater deposits. It may be that no fuel oil can be obtained commercially which will not foul heaters under certain operating conditions. It may also be that more frequent cleaning of heaters will prevent fouling. These are all questions that require considerable research. This research is under way and the prospects are that a definite

answer will soon be had after which a specific requirement for fouling tendency and a means of determining this will be added to the specification to replace the present indefinite requirements in this respect.

Stability in storage is in somewhat the same condition as heater fouling tendency with respect to what may be specified as detrimental and a means of determining that the oil delivered is stable. By stability in storage we mean that the oil remains uniform throughout and does not separate into several layers, each layer having different characteristics.

Lack of stability should be more evident in shore storage where settling is not retarded than on board ship where the motion of the vessel should retard settling of the oil into layers. This subject is also being investigated and it is expected a more definite requirement can soon be added to the specification.

The previous specification details and the present specification details follow:

PREVIOUS SPECIFICATIONS.

(*a*) Fuel oil shall be a hydrocarbon oil, free from grit, acid and fibrous and other foreign matter.

(*b*) Fuel oil shall conform to the following:

Bunker	*A*	*B*	*C*
Flash point, degrees F. minimum	150	150	150
Viscosity, Saybolt Furol, seconds at			
77 degrees F. maximum	100	.....	.....
at 122 degrees F. maximum	.....	100	300
Water and sediment, combined, per cent maximum	1	1	.....
Water, per cent, maximum	.....	.....	1
Sediment, per cent, maximum	.....	.....	0.25

PRESENT SPECIFICATIONS.

(*a*) Navy fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves.

(*b*) The flash point shall not be lower than 150 degrees F. when tested in a Pensky-Martens closed tester.

(*c*) The viscosity shall be measured at two points as follows:

(1) The viscosity in Saybolt Furol seconds shall be not greater than 750 seconds at 77 degrees F.

(2) The temperature at which the viscosity in Saybolt Universal seconds is 150 shall be not greater than 185 degrees F.

The oil as delivered shall not contain more than 1.0 per cent of total water. For deliveries by supplier's tankers or barge, oil containing not more than 2.0 per cent of total water is acceptable with a reduction in price for all water in excess of 1.0 per cent.

Note. The reduction shall be (1.25 times excess water per cent) per cent of contract price.

(*d*) Ash shall not be greater than .12 per cent.

(*e*) The oil shall have a fire point of not less than 220 degrees F. If the water content of the oil prevents an accurate determination of fire point, the oil will be acceptable if the foaming due to water starts below the fire point and at a temperature not lower than 195 degrees F. If the flash point is 175 degrees F. or higher the fire point need not be determined.

(*f*) The oil shall be free from a tendency to deposit excessively in fuel oil heaters when being heated for atomization at a viscosity of 150 S.S.U., for all rates of flow from at anchor to full power, with sudden changes of rate of flow and with steam to oil heater manually controlled.

(*g*) The oil shall be free from a tendency to sludge excessively in storage at temperatures from 40 degrees F. to 100 degrees F.

THE PLACE OF FUEL OIL IN THE NAVAL ORGANIZATION.

By LIEUTENANT JAMES E. HAMILTON,* U. S. N., MEMBER.

FUEL OIL AS A MILITARY NECESSITY.

Today every United States naval vessel in commission or under construction and all but about six, of no military value, out of commission, use fuel oil. The oil is either burned under boilers for the generation of steam or is burned in internal combustion engines of the Diesel type. At the present time there is no known means of developing sufficient power for ship propulsion except through steam or the internal combustion engine. Oil burning steam driven naval vessels are so designed that only the freest imagination can visualize the physical possibility of converting an oil-burner to burn coal. Hence it appears that as long as any vessel now built or building is retained on the list for possible service, the Navy will require liquid fuel or fuel oil.

The days of meeting emergency fuel shortages by stoking broken up furniture and other wooden fixtures have passed. A naval vessel of today will become a useless hulk when her pumps have delivered the last gallon of fuel oil on board from the storage tank to the boiler or engine. If no replenishment is possible she will remain useless.

Practically the same result may be obtained, with full or nearly full storage tanks, if the handling and burning equipment cannot adequately handle the kind of oil in the tanks. It is conceivable that with a ship equipped to handle 99 per cent of all the fuel oil produced, a bunkering with oil belonging to the other 1 per cent might render the vessel immobile and hence valueless.

In military operations, a fleet of from 200 to 400 vessels of all types might suffer very little from the inability of a small number to participate. If the inability arises unexpectedly it may entirely

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negative a well conceived plan and it is easily possible that it may completely wreck an operation and lead to disaster. When it is realized that there are cases on record, all chargeable against the fuel oil, such as: (1) Ship stopped at sea and unable to proceed because the fuel oil system was plugged up; (2) Ship at anchor unable to get underway for the same reason; and (3) A 22-knot ship reduced to a maximum speed of 16 knots because of loss of fuel oil heater efficiency due to fouling; it is apparent that the possibilities suggested in the two preceding paragraphs are not idle dreams. The conditions which arose in the three cases cited came unexpectedly and apparently with insufficient warning to permit preventive measures. The fuel in each case had been found to meet the requirements of the specifications under which it was purchased. Is there any doubt that the consequence of such casualties could be very serious or disastrous depending upon the importance of the mission on which the vessels were engaged?

This article is to be devoted entirely to fuel oil because, in the writer's opinion, it, as a munition of war, stands alone. Of the consumable supplies which are vital to a man-of-war, all except fuel can be replenished normally if the fuel lasts. Since that consideration implies available time and freedom from other duties, it cannot be considered conclusive. Volumes could perhaps be written, but the writer's reasons for singling out fuel oil can be summarized in a very few words. It is postulated that aside from ammunition, food, lubricants, gasoline, and fuel oil, ingenious naval personnel can improvise in an emergency.

Of the five commodities listed, ammunition, representing as it does, the purpose and function of the ship, is the most important. Physical limitations restrict the amount of ammunition which can be carried by any ship and there is no possibility of removing the restriction. However, once the entire allowance of shells or torpedoes has been discharged against an enemy objective, the vessel has fulfilled her major mission. If mobility fails at this point little immediate harm to the cause will be done, but if the chance of failure exists can there be any assurance that it will not come at a more crucial time? As to the quality of ammunition, that is a question which has always been considered as one for the Navy to handle and the organization provides amply for it.

The three other commodities aside from fuel oil may be grouped together. It is admitted that the failure of supply or quality of any of them might be disastrous. However, ships can be and are designed to carry a supply of each which is adequate for any possible need for several times as long as the full capacity of fuel oil will last under extreme conditions. As to quality: food, lubricants, and gasoline are all essential to industry and society and continual work is being done by many interested groups on the quality of these commodities, particularly as to means of maintaining and improving the quality. It so happens that increased production or improved quality of either lubricants or gasoline has an uncontrolled reaction on the quantity and quality of fuel oil.

GENERAL REQUIREMENTS OF FUEL OIL.

In preparing a basic specification for fuel oil many different points of view must be considered. As a naval material fuel oil must appear differently to the tactician, the logistician, the marine engineer, the constructor, the civil engineer, and the doctor. Discharge of the duties of each one may be influenced by fuel oil and each must lay down certain requirements to be met by the fuel oil. Each point of view will be briefly described.

Tactical Requirements.—The tactical commanders down to and including each individual captain should be free from detailed worry about fuel oil. The oil should be of such quality that a maximum quantity for steaming the maximum number of miles or hours can be carried in the limited space allotted on naval vessels for fuel storage; that all of the fuel oil carried can be utilized; and that no characteristic of the oil will prevent ready utilization of the full designed range of speed of each individual vessel.

Logistic Requirements.—Logistics requires that fuel oil be available in sufficient quantity *and of satisfactory quality* at the points where it will be needed for maintaining the mobility of the units of the fleet. This may be accomplished through a widely distributed *source* of original supply (refining centers); through permanent commercial marketing facilities properly distributed; or through permanent naval facilities. If the permanently located facilities are insufficient they may be augmented and made satisfactory by a sufficiency of mobile facilities.

Regardless of the arrangement for caring for the basic supply, facilities must be such that every unit of the fleet can be refueled with a minimum of time away from its military and/or fleet duties. In the interests of military control, fuel oil should in every case, be received by a combatant unit of the fleet from a naval and not a commercial activity.

The oil must be reasonably stable in storage; that is, no change which seriously affects its usefulness should take place in storage tanks, either ashore or on board ship, either for a short or a long storage period.

Marine Engineering Requirements.—From the engineering point of view fuel oil must be convertible into motive power with the maximum efficiency. The equipment must be designed for this purpose and after the ship is completed, the fuel oil used during the vessel's life must permit attainment of designed mobility with the original equipment. Specifications must be so drawn and left unchanged that the fuel oil supplied to a vessel on her last cruise will give as satisfactory performance as did that on which she ran her acceptance trials fifteen to twenty-five years earlier.

In addition to the general requirements, the fuel oil must have such characteristics that, in use, the treatment provided by the ship's equipment to remove the oil from the tanks and burn it at maximum efficiency will not react on the oil in such a way as to reduce or destroy the efficiency of any part of the equipment or of the oil itself.

Structural Requirements.—The fuel oil must be such that it can be carried in small, irregularly shaped spaces without deterioration or insuperable difficulties in removal. No treatment required in using the oil shall impose stresses on the ship's structure beyond those which it is designed to carry. Because of its large proportional weight, the fuel oil must, in certain cases where ship stability demands it, be susceptible to replacement by readily available material (sea water alone meets the requirement) of sufficient weight to compensate for the loss of weight of fuel used, without destruction of the fuel's value. The oil must be such that any of it which escapes into the bilges can be removed from water pumped overboard before the latter is disposed of, or if it goes overboard it should sink rather than float on the surface.

Civil Engineering Requirements.—Where any of the storage and shore distribution facilities for fuel oil belong to the Navy, the question of design of storage tanks and of handling equipment become naval questions. Inherently these questions are technically identical with those of marine engineering and of construction, but the difficulties are much less severe. Also, shore facilities are much more readily susceptible to modernization than are shipboard facilities.

Hygienic and Sanitary Requirements.—The fuel oil should be such that at no time should any treatment to which it is subjected on board ship result in a discharge of explosive, noxious, or toxic gases; spaces contiguous to fuel oil should not be heated to temperatures which endanger the health or comfort of personnel or which damage or destroy food or other materials, by the temperature of the oil; and the oil itself should contain no ingredients destructive of tissue or harmful to the skin.

THE SOURCE AND PRODUCTION OF FUEL OIL.

Any of the factors which enter into the source and production of fuel oil and which affect its distribution, quantity, or quality are of interest to the Navy. Some of the factors affect all three and nearly every phase of the oil industry has its effect on one of the three phases of naval fuel oil.

Production of Fuel Oil.—Fuel oil is an oil refinery product. There have been cases where crude oils have made satisfactory *marine* fuel, but not *naval* fuel. The crude oil must be produced where located by nature, transported to the refinery, and manufactured into the various petroleum products of commerce. Each individual crude oil has its characteristics and will give a maximum return of product value if subjected to the proper refinery treatment. There is a balance between the value of the products and cost of refining and successful commercial operations require that this balance be struck so as to pay the maximum net profit.

Thus a crude oil may contain valuable lubricating fractions, whose removal is possible, but for reasons of cost of equipment, cost of processing, local demand for fuel oil, or saturated lubricating oil market, may be processed to leave the lumbricants in a residuum which is sold as fuel oil; or a large demand for gaso-

line or kerosene with consequent high price may result in a further processing of what might be considered normal fuel oil to convert it into the more valuable products resulting in a smaller volume of fuel oil of different characteristics.

The preceding paragraph contains but two of many possible examples. Refinery equipment is so flexible that changes in operation can be made almost from day to day to meet changing economic and other conditions. Every successful refiner must base his current operations on his current market. The changing conditions which affect distribution, quantity, or quality of fuel oil will be considered under those heads.

Distribution of Fuel Oil.—The original distribution of fuel oil must depend on the location of refineries. In general, refinery locations are influenced by two factors: location of crude oil production and location of major markets.

The result gives four classifications of refineries: (1) large complete refineries permanently located near centers of population, (2) large complete refineries permanently located in *regions* where the production of crude oil is assured for many years, (3) small, fairly complete refineries, permanently located in a *field* of settled production for the manufacture of special products or to satisfy a local market, and (4) temporary or semi-permanent refineries located in a new flush field to take advantage of locally produced, cheap crude oil.

Bebore detailing the preceding paragraph, the writer desires to narrow the field of study by setting down certain views as to which kinds of refineries have actual naval interest. What is the position, as a possible source of naval fuel oil of: large and small refineries; large and small refinery companies; interior or coastal refinery location; domestic or foreign refinery location; and domestic or alien commercial control of refineries?

What are here expressed are personal opinions of the writer. He feels, however, that any of them which cannot be accepted as axiomatic should be subjected to competent naval consideration. This point will be discussed later.

Size of Refinery.—In order to utilize small refineries (those rated at less than 10,000 barrels of crude oil per day), with very few exceptions, it would be necessary for the Navy to provide load-

ing facilities or to accept fuel oil from such refineries under very unfavorable conditions. In general, no refinery with a rated capacity of less than 10,000 barrels per day need be considered as of any naval value unless a plan is conceived and placed in operation for providing additional handling facilities at naval expense.

Size of Refining Company.—As it happens, the question of size of refining company is very closely tied to the size of the refinery. The statement made in the preceding paragraph is also true of the company. Companies with a total refining capacity of less than 10,000 barrels per day are usually local concerns with only one refinery. In a few cases, they are regionally local with a number of small plants. The larger companies may have one large refinery or a number of smaller ones, but most of them have at least one large refinery. The larger company is, as a rule, more stable and financially stronger. It is the only one which can do fuel oil business with the Navy unless the latter establishes a partial subsidy over the company.

Location of Refinery—Local.—No refinery can be of value to the Navy unless it can deliver its fuel oil product to a seaport. Delivery may be effected in one of five ways depending on location: (1) location directly on navigable salt water and delivery direct to naval activities; (2) location less than about fifty miles from a sea terminal and delivery therefrom by a short direct pipe line; (3) location inland on a navigable waterway connecting directly with the sea and delivery by either river or ocean vessels; (4) location inland and delivery to the sea by long pipe line; and (5) location inland and delivery to the sea by rail.

The first two types can be considered as of primary importance to the Navy. The third type might enter into the picture only when the price of fuel oil has reached the point where it cannot compete in *shore* installations with coal, or under certain, usually temporary, local market conditions. At present the fourth type is of no naval value, but it is conceivable that, in a flush field, local refiners might handle the crude in topping plants and dump the residual fuel oil on the market so cheaply that it would pay to pipe it to a more complete refinery for cracking. Such fuel oil would not be placed on the bunker market as such, but it would be available at the coast in an emergency. Type five locations are of value only in extreme

emergency. For present consideration only refineries of types (1) and (2) are included.

Location of Refinery—General.—By far the greater part of the world's refinery capacity is located in the United States. There are three reasons for this and any prediction that the reasons will change in the future is not warranted. The three reasons are: the United States produces more crude oil than do all other countries combined; the United States consumes more petroleum products than all other countries combined; and the industrial development of the United States has been and is such as to foster and maintain mammoth industries such as the oil refining business requires.

Fuel oil emanating from refineries located in foreign territory should be of secondary interest to the Navy for the following reasons:

1. Normal peacetime operations of the naval forces place all units except the Asiatic Fleet within natural supply districts from domestic refineries. Occasional cruises of single vessels which require bunkering in foreign ports must be handled as individual cases as they arise.

2. In time of war any plan which contemplates utilizing fuel oil produced in foreign refineries must take into account the question of neutrality. No refinery located in a foreign land can be used for bunkering the fleet unless the territory is belligerent and subjugated by the United States or is under allied jurisdiction. The former implies a special military campaign which may or may not be a portion of the proper major plan. The latter requires pre-knowledge as to the diplomatic course of the war which probably cannot be depended upon.

3. In any operation of the fleet, supply of fuel oil from the United States will be on interior lines, no matter how extended, whereas supply from any other part of the world except the northern part of South America and the West Indies will require specially extended exterior supply lines.

4. Refineries in the United States can be kept under continual observation as discussed later, and the Navy kept apprised of the trend of fuel oil supply as to quality and quantity.

Ownership of Refineries.—The ownership of refineries is of little importance except for the possibly greater patriotic interest

of the native owner. In time of war enemy ownership might form the simplest means of entry for the military forces into the oil business to insure their own supply. If the ownership is neutral it must contribute its full share from its United States refineries or surrender to native control.

Summary.—It is the opinion of the writer, therefore, that the source of naval fuel oil is properly from large refineries owned by large companies, and located on or very near to the seacoast of the United States.

It may be of interest to note that since the first naval contract for bunker fuel oil was made in 1910, 34 companies have held contracts or orders at one time or another; that 26 of these companies are today among those which have more than 10,000 barrels per day refining capacity located on the coast; that there are only 32 such large companies today so that only six of them have never furnished naval fuel oil directly; and that of the eight other companies which have held contracts: three were marketers only and probably represented the larger companies, two were large companies which have since been absorbed by other now-existent large companies, one was a subsidiary of a large company, and only two were small companies. These last two held contracts for small local supply of bulk delivery.

To return now to the distribution of fuel oil: If the Navy is to accept the limitations just suggested, there are four geographical areas to be considered. They are:

1. The Atlantic Coast with refinery centers at Baltimore, Philadelphia, New York, Providence, and Boston.

2. The Gulf Coast with refinery centers at New Orleans, Port Arthur, and Houston.

3. The Southern California Coast with refineries grouped in the Long Beach-Los Angeles-Wilmington area; and

4. San Francisco Bay.

Of the four areas, the Gulf Coast and Southern California are based on the regional long-time production of crude oil and the other two are based on markets and centers of population.

The refineries on the East Coast depend to such an extent on crude oil brought to them by ocean tankers, that any interference with coastal shipping would jeopardize their existence. One of

the Navy's wartime missions, absolutely essential to the petroleum industry, will be the protection of tanker routes from the Caribbean and the Gulf of Mexico. Hence the East Coast refineries must be considered as a secondary source of fuel oil. In any special case of need of fuel oil in the North Atlantic, it must be decided whether the greater advantage will accrue to the Navy in taking over its fuel oil in the Gulf and carrying it to destination or to protect the shipment of sufficient crude oil to permit the East Coast plants to produce the fuel oil closer to the point of need.

The San Francisco Bay area depends on crude oil shipped in from the south, but the dependence on naval protection is not so great as is the case on the East Coast. Not only is the sea distance from crude shipping points not so great, but also a considerable amount of crude oil is shipped in by pipe line. However, since an active submarine campaign and sabotage on shore could conceivably cut off the supply of crude oil to San Francisco, it must be considered as a secondary source.

We are thus reduced to two primary sources of fuel oil for naval use: the Gulf Coast of Texas and Louisiana, and the Long-Beach-Los Angeles area of Southern California.

Each of the two primary and two secondary sources of fuel oil supply has a primary and secondary source. Which is to be considered primary is a matter of opinion. One is the currently produced product which is available for marketing as fuel oil and the other is the accumulation of products which is held in storage as fuel oil stocks and so accounted in statistical reports.

In addition to the above sources of fuel oil there are the marketing stocks distributed by the various companies in such a way as to best handle their particular markets. The writer has no data on this storage, but considers that it should be classed as tertiary and of minor importance, while admitting that in a particular case it might be of the greatest importance.

THE QUANTITY OF FUEL OIL.

The quantity of fuel oil available at any time depends on a number of factors. The general consideration requires that the matter be divided into two parts: stored fuel oil and current production.

There are no known published data on which to base estimates of the value to the Navy of oil in storage. It will be assumed that the fuel oil owned by the Navy and stored in naval tanks is satisfactory for use. The Navy's storage, however, is limited and cannot be considered as sufficient to constitute an emergency reserve. The Navy's efforts to obtain an adequate reserve of this nature have been unavailing and other sources must be depended upon for the reserve of stored oil. However, such naval storage as is available must be watched since the nature of fuel oil is such that satisfactory fuel oil may, after ten years, more or less, of storage, be valueless.

Fuel oil in commercial storage may be of any of a dozen or more different kinds. The generic term under which fuel oil is classed statistically, covers everything from the kerosene-like grades of domestic heating oils to the heavy viscous residuals oils which are so difficult to handle that they are valueless, but which are run into storage because it would be too expensive to dispose of them otherwise.

Even if data were available to tell how much of the stored oil was satisfactory naval fuel oil, changing conditions might make it profitable for a refiner to reclassify some of it as charging stock for cracking to finer products. If this were done, the fuel oil which is currently considered as available in commercial storage for emergency naval use, might be charged to refineries for the manufacture of finer products and disappear very rapidly. This is just one of the phases which must be constantly watched if any plan is to consider the use of refinery stocks of fuel oil.

The amount of fuel oil currently produced will be the result of the economic balance previously mentioned. If fuel oil production could be independently controlled, the amount produced would approximate the market demand. However, it is still in the position of being the by-product and must be forced on the market in excessive quantities at times and denied to the consumer at others. The principal factors which influence the amount of fuel oil produced are: amount and character of crude oil available for refining; and the demand for gasoline, kerosene, and light burning and heating oils.

THE QUALITY OF FUEL OIL.

Quality can be considered under two heads: chemical and physical characteristics.

Chemical Characteristics.—The chemical characteristics of a fuel oil depend on the chemical elements which are present and the chemical combinations or compounds in which these elements exist. No compound can be present unless the fuel oil contains the necessary constituent elements, and it seems impossible that any element can be present unless it was present in the original crude oil or was added at some point in the refining or storage process, either intentionally or fortuitously.

The writer believes that today a challenge could be issued to all chemists, refiners and engineers and that not one of them could conclusively prove that any particular element or compound is either highly desirable in or damaging to a fuel oil. At the same time it is believed that most of them would express an opinion that many elements and compounds, possibly present in fuel oil would cause wide variations in its characteristics, many of which might be vital in use.

Compounds present in the oil may be a result of the original compounds in the crude or of chemical recombination during the refining process or during storage in the presence of air. The possibility that certain compounds may be formed in storage or heating on board ship must be borne in mind, but any such formation must necessarily depend on the presence of the necessary material in the oil as furnished.

Physical Characteristics.—In general, there can be no question that the physical properties of a fuel oil are direct functions of its chemical characteristics. The information on this point is very limited. Very little research work has been done on fuel oils toward correlating physical and chemical properties. It has always been assumed that if a few physical characteristics of a fuel oil were specified, the oil would be satisfactory.

It is a comparatively simple matter to lay down certain physical requirements for fuel oil. One point which has been stressed by the Bureau of Engineering for about fifteen years, and one which is dictated absolutely by naval conditions of supply and purchase. is that the specified physical characteristics of fuel oil should con-

form fairly closely to those of the bulk of fuel oil normally produced.

It must be accepted, pending further investigation, that rules established years ago still hold. Among these may be mentioned the following:

1. Fuel oil may be made sufficiently fluid for pumping by raising its temperature.

2. There is an optimum fluidity at which the atomization of fuel oil attains a maximum efficiency and this point can be reached by raising the temperature.

3. The trend in the production of bunker fuel oils is toward higher viscosity, that is: lower fluidity.

One assumption based on the above statements is now believed, by the writer, to be fallacious. This is: as the fuel oil becomes more viscous it can be handled and burned by naval vessels by the installation of additional heating capacity in the storage tanks and service heaters.

This belief is based on the fact that the common residual fuel oils of today and probably of the future are products of cracking processes where the oil has been subjected to high temperatures and pressures and has undergone considerable chemical alteration.

It is safe to state that all of the scientific and quasi-scientific work which has been done on fuel oils in the past has been done on natural or virgin straight run residues. Much work which has been done on lubricating oils has been found to check roughly with straight run fuel oils and has, in the past, been applied to fuel oils.

There is an unlimited field for research work on the properties of fuel oils and on much of it depends the answer to questions which are of vital interest to the users of fuel oil and to the Navy in particular.

ORGANIZATION REQUIREMENTS.

It has been shown that the Navy is interested in fuel oil as regards its quality, quantity and distribution. No separation of the first from the last two is tenable. Only oil of satisfactory quality is of any value to the Navy and only the quantity and distribution of such satisfactory fuel oil can be considered.

It has been further shown, or at least sketchily indicated, that the three factors of quality, quantity and distribution are all affected by practically every phase of the operations of the oil business from geologic discovery to final marketing.

It is now proposed to outline the needs of the Navy as regards information, investigation, experiment, equipment, and plans for the proper handling of the fuel oil situation. It will be necessary first to explain the writer's reasons for advocating a permanent place, more definitely specified in the naval organization for fuel oil than is now provided. The vital importance of fuel oil must be recognized and the constant rapid changes in the fuel oil situation must be realized. A review of the history of fuel oil in the Navy shows that at numerous times temporary boards have been convened to study the question. In some cases the board has made definite recommendations based on a study of the current situation. In other cases the temporary nature of the board prevented completion of its work because it happened to run into the need for certain definite investigation before proceeding. Either a recommendation that the required investigation be made was submitted or the board itself began the investigation which could not be completed before circumstances dictated the dissolution of the board. Then, in the absence of any activity specifically charged with carrying on the work of the board, the work stopped, rapidly passing into obsolescence.

It is suggested that if some office in the naval organization is specifically designated as responsible for studying all phases of the fuel oil question to the exclusion of others and for making and following up necessary recommendations to the bureau or office charged with the material involved, the organization will carry pending work over inevitable changes of personnel and the Navy will be constantly up-to-date as regards fuel oil. It is intended first to outline a general plan which should permanently provide for handling the fuel oil question. This plan will be too idealistic from the naval point of view to be feasible and modifications will then be made to make it entirely practicable with as little decrease of effectiveness as is possible. Unfortunately, the ideal plan is much simpler in operation than is the practical one.

THE IDEAL PLAN.

The simplest method of controlling quality, quantity, and distribution of fuel oil would be for the Navy to exercise the control directly upon its own agencies and not through commercial activities. Such control would necessitate ownership and operation of the following coordinated activities:

1. Ownership of proven oil fields containing a minimum of 30 years' supply of fuel oil. This would allow 10 years for perfecting replacement fuels and 20 years additional for making any necessary conversions in ships.

2. A purchasing organization for the purchase of *crude* oil in amounts currently needed and in competition with commercial refineries.

3. A topping and blending plant (refinery) with a fuel oil capacity double the normal peacetime requirements of the fleet.

4. Reserve fuel oil storage tanks located in the safest place close to each probable main field of fleet operation.

5. Current fuel oil storage tanks located at each Navy yard and fleet operating base.

6. Tank ships sufficient to distribute the fuel oil from the refinery to the storage tanks and if needs be to carry crude oil to the refinery.

7. Fleet tankers sufficient for servicing the fleet when assembled and operating under war conditions at the maximum probable distance from a reserve storage.

8. Fuel oil barges for local service at operating bases.

The above equipment should not, if properly handled, increase the Navy's fuel bill and it would insure an absolutely secure and sufficient supply of fuel oil for current needs or for any emergency. Properly administered, it could be available as an adjunct of the fleet which would be relieved of all anxiety as regards fuel supply.

It would be necessary to provide for an initial outlay of considerable size. The cost would be well worth while even though it were charged off when expended. It is believed, however, that the entire capital charge could be amortized in a reasonable length of time and included in the cost of the fuel oil used or stored. The stored fuel oil would at all times constitute a capital investment which would have to be carried as a charge to national security.

This is a legitimate charge, either with the ideal or the practical plan to the extent that the Navy General Board considers reserve fuel oil storage to be necessary.

The ideal plan, in more detail, would require the following:

1. Underground reserves in California and Texas, the former already available in Naval Petroleum Reserve Number 1 and the latter to be obtained through proper legislative or executive action. These reserves would be thoroughly investigated and detail plans made for their development but they would not be drawn upon until the Navy Department had definitely decided that the supply of crude had begun the inevitable final decline.

2. Plans should be made for building a pipe line for exclusive naval use from each of the reserves to the naval refineries. Funds for operation of the reserves and for construction of pipe lines should be constantly available without the necessity of waiting for congressional action. In connection with the purchase of crude oil to supply naval refineries, it might be desirable to construct a portion of this pipe line at once.

3. Two refineries or topping plants, one located in the neighborhood of San Pedro, California, and the other at Port Arthur or on the Houston Ship Channel, Texas. A survey of the field at any time would probably reveal several small refineries in each region which could be purchased cheaply and used as a nucleus for the naval plants. These refineries would be supplied with crude oil purchased in fields of the region and delivered by pipe line or purchased in foreign fields and brought in by naval tankers. The refineries would operate at full capacity until all of the storage decided to be necessary was filled and then would reduce operations to just care for the current needs of the fleet, plans being maintained for immediate expansion to full capacity in the event of an emergency.

The refineries would, as a rule, operate on a type of crude which could be subjected to a fairly light distillation to make a satisfactory residual fuel. This fuel would offer no difficulties whatever in use. Advantages could be taken of any very heavy crude oil which appeared on the market very cheaply, by blending the residue from this crude with a portion of the distillate from a lighter crude. Either type of fuel oil would be entirely satisfactory for use in

the present equipment of vessels and future designs could be independent of possible variations in the nature of commercial fuel oil.

Except for such of the distillate as may be currently needed for blending when crudes of the heavier types are processed, all of the distillate should be placed on the market and sold. It is believed that, in the most unfavorable case, the distillate would sell for enough more than the cost of crude to pay for the refining cost and bring the fuel oil price well below the crude oil cost price.

The refineries would be ready to handle the production from the petroleum reserves at whatever time they were placed in production.

4. Reserve fuel oil storage should be located where and in such quantities as determined necessary by the General Board. Suggested quantities would be five million barrels located at each of the following places: Puget Sound, San Francisco Bay, San Diego Bay, Pearl Harbor, Panama Canal Zone, Guantanamo Bay, Chesapeake Bay, and Narragansett Bay.

Plans should immediately be drawn for the complete storage plants and land obtained. Construction of tankage should proceed at the rate at which fuel oil in excess of current needs is produced at the refineries. Each plant should have facilities for loading and unloading tankers and should be maintained by a small civilian force under the command of a line officer.

5. Current storage should be provided at every Navy yard sufficient to provide for fueling all vessels after Navy yard overhaul periods. The amount in storage should never fall below the minimum necessary to fuel every ship out of commission in the yard to capacity.

6. At every fleet operating base sufficient storage should be provided to augment the force of the fleet tankers and possibly to divert these tankers to the carriage of oil to reserve storage tanks at certain periods. It might be advisable to use floating hulks for this storage so that it can be moved from place to place when changing conditions dictate a change of base. It is apparent that, in certain locations, one group of tanks will serve two or three of the purposes described under "4," "5," and "6."

7. The tanker fleet should comprise two general types of vessels. The characteristics, of course, should be set down by the General Board but the following suggestions are offered:

(*a*) Fleet tankers for service of vessels of the fleet—about 16 knots, turbine driven, with a cargo capacity of about 7500 tons of fuel oil and defensive armament.

(*b*) Cargo tankers for carriage of fuel oil to storage—about 10 knots, Diesel driven, with a cargo capacity of about 12,000 tons and no armament.

The number of fleet tankers should be sufficient to provide a cargo capacity of at least the total monthly fuel consumption of the fleet. The number of cargo tankers should be sufficient to handle about one ship load per day from each of the two refineries and to carry it to the storage tank at average distance from the refinery.

8. Each storage tank group should have at least one fuel oil barge for fueling casual ships which are unable to make the oiling dock. A number of barges should be assigned to the fleet to be used at its convenience when operating at any main base.

The plan outlined above could be placed into the present naval organization with no difficulty whatever. An officer directly under the Secretary could administer all activities through existing shore and fleet establishments.

The plan would give the Navy complete control of the distribution, quantity, and quality of its fuel oil dependent only on the quantity of crude oil available. The Navy's crude oil requirements would be less than 4 per cent of today's production and of this about half would go back to the commercial market as a very valuable product. It would insure a supply of fuel oil of a type which is known to be satisfactory for naval use and stable in storage. It would entirely eliminate, as far as the Navy is concerned, the variations imposed in the quality of fuel oil today by the market demand for gasoline and other products.

The ideal plan will now be dropped because of two probably insurmountable difficulties. These are the high initial cost, the necessity for which would have to be proved to Congress; and the probable impossibility of proving that the manufacture of *naval* fuel oil was not competitive with private business. Accepting the strength of these two objections, we must attempt to adapt the ideal plan to practicability.

THE PRACTICAL PLAN.

Having abandoned the ideal plan as impossible of attainment, it must be recognized that each requirement which cannot be provided by Navy owned equipment must be provided by commercial equipment of a similar nature. Since this is so there are certain general considerations which must be borne in mind. These will be mentioned.

1. The oil business is highly competitive and hence the Navy's dealing with one company to that company's financial advantage will be protested and resented by other companies.

2. The Navy's method of purchase is strictly competitive and hence any attempt at secrecy in perfecting war plans for the supply of fuel oil will fail if it requires any financial arrangement in advance. In fact the absolute need for full interchange of information between the Navy and the oil industry prevents any secrecy and requires that the entire fuel oil problem be set out publicly.

3. Oil companies operate for profit and the Navy is not justified in accepting any allocation of equipment which imposes a financial burden on any company without paying for it.

4. The Navy should provide during peace for its own training and supply and should maintain its plans for war. It should not have to lay its fuel oil supply problem before the oil industry on the outbreak of war for the industry to handle.

5. No war plan evolved by the Navy should depend for success on the use of equipment which may be badly needed by an oil company for commercial business. The Navy should be in a position to safeguard the interests of American industry during a war to the extent permitted by the enemy and should make no plan which deliberately makes an avoidable sacrifice of commercial enterprise to the military campaign.

Review of the "Ideal Plan" indicates a logical division of any plan into the following subjects: Supply of crude oil, distribution of crude oil, supply of fuel oil, distribution of fuel oil, and the use of fuel oil. Each subject will be studied separately and then they will all be coordinated in the final plan

Supply of Crude Oil.—The supply of crude oil should be divided into general or commercial supply and Naval Petroleum Reserves. It will be considered that wells producing liquid petroleum oil,

shale deposits, coal deposits, and lignite deposits all constitute possible sources of *crude* oil. The practical technique is actually available for producing a crude oil from each of the natural sources and as the cheapest source (well oil) becomes depleted the others may be expected to come into use.

Commercial Supply of Crude Oil.—The interest which the Navy has in the general supply of crude oil is principally quantity, secondarily quality, and lastly location. The Navy's organization should provide sufficiently for a study of discovery of new fields; decline of old ones; improved methods of production; improved technique in the distillation and hydrogenation of shales, coals, and lignites; and the economics of production to permit it to make decisions based on the future supply of crude oil. This requirement is necessary for the ideal plan as well and in that plan would be charged to the office mentioned as directly under the Secretary.

The duties of following the crude oil supply are now handled by the Director of Naval Petroleum Reserves and should be specifically designated as one of the duties of that Officer. For foreign information, sufficient detail should be obtainable from trade journals and government publications, a complete list of which should be subscribed to for the Petroleum Office.

For production in the United States field offices should be maintained. At least three such offices should be organized and specifically instructed as to the type of information which is required. The three locations should be California, Texas, and New York. The first two would be located in the midst of oil producing regions and could cover any newly discovered fields which might influence the marine fuel oil supply. The New York office would gain its information indirectly through the many oil company offices which are located in that region. Specific recommendations will be deferred to the final section of the paper.

NAVAL PETROLEUM RESERVES.

The requirements of petroleum reserves for the Navy as set down by the Fuel Oil Board of 1916 have been realized with one exception. The Navy still has no reserve nor has it any prospect of having one so located as to be of any value as a source of fuel oil on the East Coast. The oil which may be produced from Reserve

Number 3 in Wyoming could be piped to the Gulf Coast via Kansas City but any such shipment, to be economically justified, would indicate such a crying need for petroleum that popular opinion would allow the Navy to have very little of it as fuel in a supply emergency apart from war.

The Federal Oil Conservation Board has reported the fact that Reserve Number 2 in California is of little value as a reserve and has recommended that, if one can be found, another Naval Petroleum Reserve be set aside to replace it. It is believed that the Navy should press this point with every effort and that the replacement reserve should be readily accessible by pipe line to the Gulf Coast.

If existing pipe lines are considered to be available for the movement of Navy crude oil from Naval Reserves, it must be realized either that unless there is pipe line capacity in excess of commercial needs, shipment of Navy crude will displace commercial crude. Except for a serious misunderstanding between the Navy and the oil industry such as arose in 1920, there is no reason why Navy reserve oil should be produced as long as commercial production can fill pipe lines and furnish all of the crude needed. If the San Joachim Valley production, for example, declines to the point where Navy oil can find room in the pipe lines, will the companies which own the lines maintain them for possible future use by the Navy? A similar question arises as to commercial pipe lines from a possible reserve in Texas or Oklahoma.

The writer finds it very difficult to picture the actual circumstances under which the Naval Petroleum Reserves will be used. There are several possibilities:

1. When commercial production begins to decline and the proper authorities decide from the evidence that no new discoveries can be expected, the naval reserves may be used to maintain the total production at the required level as long as possible. This implies that the production from the reserves will lose its identity as such and enter into the distribution of commercial crude from which the Navy will continue to draw its petroleum products. In this case, the depletion of the reserves would be more rapid than is customary with commercial fields because, as the only flush field, the demand on it will be tremendous.

2. While commercial production is still adequate, either high price of fuel oil because of prospective shortage or an absolute lack of fuel oil because commercial practice has reached the point of cracking 100 per cent to gasoline and coke, the reserves may be opened up for the Navy's sole benefit. This would require displacement of commercial crude from existing pipe lines and refineries or would force the Navy to build and operate its own.

3. When the decline of crude production begins and shortages and high prices set in as in the first case, the Navy may produce its own oil for its own benefit. The Navy, in this case, would have enough oil for many years while the rest of the country was paying excessive prices or doing without. The Navy should be able, in this case, to find idle pipe lines and refineries which it could buy or lease but it would be forced to withstand tremendous political pressure to prevent the situation from being changed to the first one described.

No differentiation has been made above as between peace and war. During peacetime many difficulties can be accepted which would have to be overcome during war but a deficient supply of fuel oil is not one of them. Sufficient fuel oil must be available at all times for the proper training of the fleet. Admitting that training requires but one-third to one-fourth as much fuel oil as wartime operations, the supply of that quantity must be assured. Also the supply must be such that the 200 or 300 per cent increase can be met in a very short time with very little warning.

In addition to the detailed plans which should be constantly available for the operation of the reserves and the transportation of the oil produced, the Navy should be constantly in touch with the commercial situation so that general plans for the utilization of the reserves can be kept current.

Distribution of Crude Oil.—The matter of oil pipe lines as they affect the transportation of crude oil from the Naval Petroleum Reserves has already been touched upon. As the reserves, now located in important producing regions, become isolated due to the depletion of non-reserve fields, the possibility of finding commercial pipe lines available for moving the Navy's oil will diminish and such pipe lines may have to be built by the Navy.

Another factor connected with the distribution of crude oil is the allocation of commercial tankers. When the principal function of tank ship movements is to distribute the finished products to each individual company's markets, there is a strong possibility that many tankers can be diverted to the Navy's use in an emergency by a reallocation of the markets. When, however, the supply of crude shifts so that the principal function of the tanker becomes the supply of crude oil to refineries, any reallocation might result in a dearth of crude oil in the United States which would dangerously limit the supply of petroleum products for essential commerce and industry.

The third factor of distribution of crude oil of particular interest to the Navy is the sea lanes which will have to be positively protected, first to insure the fleet's supply of fuel oil and second to insure the supply of petroleum products for industrial, commercial, and social use in the United States.

Supply of Fuel Oil.—If the commercial supply is to be depended upon for the Navy's fuel oil, it is under this head that the greatest difficulty will be encountered. Naval vessels are built with certain equipment and this cannot be modified overnight. On the other hand, the characteristics of fuel oil available on the market may change quite rapidly due to any of the factors previously mentioned.

The Navy cannot build up an organization to handle this problem satisfactorily, independent of the oil industry. It is absolutely essential that the industry cooperate and the machinery should provide for this.

The following tabulated procedure is recommended for the Navy. The actual organization to provide for the procedure will be covered in the final section of this paper.

1. Using published data, prepare a list of every refinery in the United States which is so located that it may be in a position to furnish fuel oil in marine trade.

2. Conduct an actual survey by officer personnel of all refineries listed to classify each one as a "probable," "possible," or "unlikely" source. Prepare three lists in accordance with this classification.

3. Treat all commercial fuel oil storage tanks in the United States similarly to refineries in "1" and "2" above.

4. Consider the "probable" refineries and storage tanks as available for replacement of the naval refineries and tanks required under the ideal plan, and formulate logistic plans on these data both for peacetime and wartime supply of fuel oil.

5. To keep the plans up-to-date constant information should be obtained as to any changes in refinery equipment or technique in every "probable" refinery. Data should be obtained on the quality of fuel oil stored in each "probable" tank and information should be currently obtained as to changes in the stored oil due not only to withdrawals and refillings but also to time in storage. In this way the amount of *satisfactory* stored fuel oil at any time will be known.

6. Maintain surveillance over all "possible" and "unlikely" refineries and tanks and all new construction for the purpose of keeping the "probable" lists revised and up-to-date.

7. Formulate plans to cover the actual needs of the Navy in reserve and current use storage capacity and urge on Congress the construction of the necessary storage in such places as are not cared for by commercial storage.

8. Restrict bidding on fuel oil purchases to *refineries* on the "probable" list. Require all bidders to indicate the *refinery* in which the fuel oil offered will be produced.

9. Maintain an inspection service in each of the refining regions. Test the current output of every refinery on the "probable" list frequently and of those refineries which are furnishing oil on current contracts almost constantly.

10. Obtain frequent samples from all "probable" refineries, first small samples for critical laboratory examination and second large samples for simulative service test at a "fuel oil" laboratory.

11. Establish a fuel oil laboratory for the purpose of testing all samples and for constantly correlating laboratory and service results of tests.

12. Establish positive friendly relations not only with the sales force but the technical staffs of the oil industry by keeping them at all times informed of the Navy's problems and needs, and by active participation by selected Naval Officers at meetings of technical societies such as the American Petroleum Institute, the American Society for Testing Materials, and the American Chemical Society.

13. Increase the number of "Engineering Duty Only" Officers sufficiently to permit filling the billets listed in the following section from this group of officers.

14. Build up a staff of technical civilians to fill the billets listed in the following section.

Distribution of Fuel Oil.—This subject has to do with the use of commercial tankers, barges, and loading facilities in place of those owned by the Navy under the ideal plan.

It requires a survey, kept up-to-date, of all tankers and barges in existence under the American flag, under foreign flags of American ownership, and under possible enemy flags and/or ownership. The survey should show not only the characteristics of each vessel but also its availability at any time. This last would depend on the type of service being performed by the vessel and on the importance of this service both to the ultimate fuel oil supply of the Navy and to the general supply of petroleum in the case of American vessels; and possibility of capture of enemy vessels.

Only vessels which, at any particular time, can be considered as divertible to fleet service without endangering some phase of the general supply should be counted on as available for replacement of required naval tankers and barges. Any deficiency in commercial facilities should be immediately reported to Congress with a request for construction of additional naval tankers or barges. Such tankers as are built and owned by the Navy should be kept modern by the same kind of a replacement program which should apply to combatant vessels.

The Use of Fuel Oil.—The study of the use of fuel oil in the past has considered such use from the point of view of the equipment much more than of the oil. This should be changed and the only way of doing so is by adequate sampling and testing of the oil used in connection with every laboratory test of fuel oil equipment and with the service use of oil on board ship. The only requirements would be the laboratory previously mentioned, proper instructions and information for the forces afloat, and adequate properly conceived reports from the service.

It is only by constant study that any subject which is constantly changed can be learned. The Navy has never provided adequately for the study of fuel oil in all of its phases and it is here proposed

that this now be done by a definite provision in the naval organization. It will be shown in the following section that the change required will not be so radical as to prevent it nor will the cost be excessive.

THE RECOMMENDED ORGANIZATION.

All that has been said has been necessarily sketchy in the interest of brevity. No one point has been completely developed nor definitely proved. The intention has been to indicate the intricacies of the problem, the necessity for some means of handling it, and the general desiderata of the means selected. If this intention has not been realized the writer has failed of his purpose. The following definite arrangement is offered as meeting the needs of the case satisfactorily with the minimum of change and expense and the maximum utilization of existing facilities.

This paper contains a very definite criticism of the existing organization but none whatever of any existing activity. The Navy has been fortunate in having gotten along without an organization similar to the one proposed, principally because of occasional effort on the part of individuals whose interest has extended beyond the designated confines of their jobs. The Bureau of Engineering is especially to be commended for having carried on so well without the necessary authority and the essential military direction.

When Lieutenant Commander J. J. Halligan, U. S. N. (now Rear Admiral), completed his duties as head of the Fuel Oil Board in 1916 he recommended by letter to the Secretary that an office be created under the Secretary for the coordination of the fuel oil problem and for handling all phases of the problem not specifically charged to some other office or bureau. No action on this recommendation can be found until about 1920 when such an office was formed in the Bureau of Engineering but directly under the Secretary of the Navy. Lieutenant Commander (now Captain) H. A. Stuart, U. S. N., was ordered to this office and he and his successors functioned as "the oil office" until the oil scandals broke. At that time all records were transferred to the Secretary's Office and the Bureau of Engineering was stripped of all connection with the Naval Petroleum Reserves which were only a portion of the interests of the office which now no longer exists.

Later the Director, Naval Petroleum Reserves, was designated under the Secretary and judging from the reports of the Director, that office has been entirely occupied with affairs of the Naval Petroleum Reserves.

Thus the principle of the office which is to be the cornerstone of the proposed organization is not original with the writer. Had the oil scandals not appeared, to focus the Navy's fuel oil views entirely on the Naval Petroleum Reserves, it is believed that the proposed office would now exist in some form.

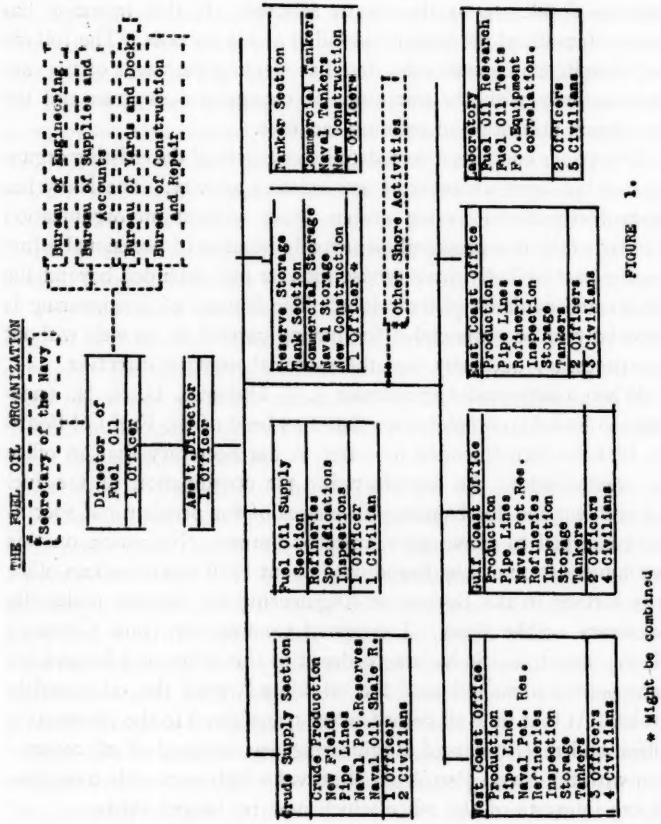

FIGURE 1.

The proposed organization, with what the writer considers a minimum of personnel, is shown on the chart, Figure 1.

As regards personnel, a summary of Figure 1 gives a total requirement of 15 officers and 19 civilians. The number is in addition to present personnel in all existing activities except the Office of the Director of Naval Petroleum Reserves, the offices of Inspectors of Naval Petroleum Reserves at Los Angeles and Casper, the office of the Resident Inspector of Naval Material at Wilmington, California, the Inspector of Fuel Oil attached to the Naval Supply Depot, Brooklyn, and the fuel oil research unit at the Naval Research Laboratory; all of which offices would be transferred into the new organization. As the present activities employ six officers and nine civilians, the proposed organization will require an increase of nine officers and ten civilians. The present is not a propitious time to propose new needs for naval personnel. However, the desirability of placing naval fuel oil on a stable basis as soon as possible prevents withholding the proposal until a more favorable opportunity.

The present is an excellent time for obtaining civilians of experience and ability for permanent naval positions and if the urgency of the situation is appreciated, it should be possible to allocate the necessary officers. Aside from the salaries of personnel the only other item of major expense would be traveling expenses which should be large enough to permit the freest movement of all "oil" personnel. Other expenses would be nominal.

In setting up the organization one additional item is vital. This is the question of appropriation. Under the Secretary of the Navy in both the Budget and the Appropriation Bill should be a heading "Fuel Oil" under which should be included all appropriations for maintenance of the organization; maintenance and new construction of all fuel oil storage tanks, plants, and facilities; maintenance and operation of the Naval Petroleum Reserves; construction or modernization of naval tankers; fuel; inspection of fuel; and fuel oil research and investigation. The reason for considering this point important is that it is contemplated that all of the detailed studies upon which requests will be submitted to Congress for money in connection with any of these matters will be made by the fuel oil organization. Each appropriation must

be justified before a committee of Congress and the person charged by law with the responsibility of expenditures under an appropriation is the one who is required to testify before the committee. It would require too much space here to expand this subject fully and to cite examples to substantiate the argument. Suffice it to say that the writer believes this one point to be the one which might easily wreck the work of the organization if it should be established with the present system of appropriations.

The organization, Figure 1, requires the establishment of five activities, three of which already exist in a partial form which can be used as a nucleus for the perfected organization. The five activities with the proposed duties of the internal organization of each are given below.

The Fuel Oil Office.—This office would be located in the Navy Department directly under the Secretary of the Navy.

It would originally be built up on the present Naval Petroleum Reserve Office as a nucleus.

It would study all matters connected with the supply of naval fuel oil and to facilitate this, it should be organized in four sections, as follows:

Crude Oil Supply Section.—This section would take over the present duties in connection with the Naval Petroleum Reserves and Oil Shale Reserves; would maintain current plans for the utilization of the Reserves; would study the possibility of obtaining additional reserves; would maintain current data on the commercial supply of crude oil; would maintain current information on pipe lines existing and proposed which affect the delivery of crude oil to seaboard; would keep abreast of the developments in the distillation and hydrogenation of coal and oil shales; would hold membership in the Production Section of the American Petroleum Institute; and would keep the Director of Fuel Oil fully informed by making pertinent reports and recommendations on subjects of particular interest and as requested by the Director.

Fuel Oil Supply Section.—This section would maintain current data on all refineries which are so located as to possibly affect the supply of marine fuel oil; would keep abreast of the development of refinery technique and equipment; would keep informed on the quality of the current output of fuel oil of all refineries; would

be responsible for the preparation of naval fuel oil specifications; would cooperate with the Federal Specifications Board subcommittee on petroleum products; would be responsible for the methods of test of fuel oil used by the Navy both in purchase and in use on board ship and for the proper instruction of naval fuel oil inspectors; would hold membership in the American Society for Testing Materials, the American Chemical Society, and the Refinery Section of the American Petroleum Institute; and would keep the Director of Fuel Oil fully informed by making pertinent reports and recommendations on subjects of particular interest and as requested by the Director.

Reserve Storage Tank Section.—This section would keep current records on the condition and facilities of each naval storage tank; would keep current records on all commercial storage tanks which contain satisfactory naval fuel oil; would keep informed on the characteristics of all stored fuel oil; would study the problem of the physical and chemical changes in stored fuel oil; would make recommendations on the type of fuel oil storage to be constructed and its location and amount and on any changes to be made in existing storage; and would keep the Director of Fuel Oil fully informed by making pertinent reports and recommendations on subjects of particular interest and as requested by the Director.

Tanker Section.—This section would keep informed on the military needs of the fleet for fleet tankers and on the supply problem needs for cargo tankers; would keep current data on all commercial tankers as to types, characteristics, and availability; would recommend characteristics of tankers to be built by the Navy and the number of them and on any changes desired in the characteristics of existing tankers; would hold membership in the Transportation Section of the American Petroleum Institute; and would keep the Director of Fuel Oil fully informed by making pertinent reports and recommendations on subjects of particular interest and as requested by the Director. One officer might perform joint duties as head of both the storage and the tanker sections.

The Fuel Oil Office.—The office itself would then, in the person of the Director or his assistant: administer the expenditures of the fuel oil appropriation through the proper material bureau or Commandant or Officer-in-Charge of a shore activity; would make

recommendation to the Secretary of the Navy direct or through the General Board as to the number and types of tankers and capacity and location of storage tanks needed; would make full recommendation each year as to the appropriation required for properly carrying out its functions including fuel for the fleet and new tanker and storage tank construction; would maintain liaison between the Navy Department and the leaders of the petroleum industry; would hold membership in the American Petroleum Institute; and would maintain at all times such public relations and such an organization that the civilian super-agency which will probably be required in case of a major national emergency can take over the duties and records of the office and can function with a minimum of loss to either the Navy or the oil industry.

The West Coast Office.—This office would be located at either Los Angeles or San Francisco, California.

It would be built up on the present office of the Inspector of Naval Petroleum Reserves in California as a nucleus.

The duties of the office would be: to maintain full contacts with the proper personnel of the oil business in California to permit it to keep the main office supplied with all of the information required by it as regards crude oil production, refineries, pipe lines, storage tanks, and tankers. The office should periodically inspect all naval fuel oil facilities in the Pacific and all commercial refineries and other facilities. It would supervise the maintenance and current operations of the present Naval Petroleum Reserves and oil shale reserves using the field personnel now available on those reserves. It would inspect every delivery of fuel oil on the West Coast at the point where the oil passed from the hands of a commercial to a naval activity and would maintain a small testing laboratory for the purpose of making routine tests. The principal duties of this office, repeated for emphasis, would be the maintenance of proper relations with the regional oil industry and the supply of necessary accurate information to the Director of Fuel Oil.

The Gulf Coast Office.—This office would be located at New Orleans, Louisiana; Houston, Texas; or Port Arthur, Texas.

There is no existing activity in the district which could be used as a nucleus for the office.

This office would perform all of the duties outlined for the West Coast office for the district covering the Gulf Coast and Guantanamo and the Panama Canal Zone. In the absence of Naval Petroleum Reserves the only duties of this office in such a connection would be to keep well enough informed of the regional situation that it can keep the Director of Fuel Oil fully informed of any and all possible Naval Petroleum Reserves which might be obtained.

The East Coast Office.—This office should be located in New York City. There is no existing activity in the district which could be used as a nucleus for this office.

The duties of this office would be the same as those of the West and Gulf coast offices except that there would be no duties in connection with Naval Petroleum Reserves.

The Fuel Oil Laboratory.—The formation of a fuel oil laboratory appears to offer the least practical difficulty. In the Philadelphia Navy Yard, the Naval Boiler Laboratory for the testing of fuel oil equipment is already in existence. At the Naval Research Laboratory, a fuel oil section with a fully equipped laboratory and three chemists exists. The only requirement to effecting the proposed laboratory would be the transfer of the Naval Research Laboratory equipment and personnel to Philadelphia where a relatively small addition to the buildings of the Boiler Laboratory could house the new "Fuel Oil Section." Full cooperation between the fuel oil section and the now existing equipment section could be effected by having the entire laboratory under a single director. The equipment section's technical direction and financial support would continue to come from the Bureau of Engineering while those for the fuel oil section would come from the Director of Fuel Oil.

All problems arising at any desk in the fuel oil office would be laid before the fuel oil laboratory for the necessary research, test, or development.

CONCLUSION.

The proposed organization is built up entirely on a discussion of fuel oil with *bunker* fuel oil particularly in mind. With the establishment of a Diesel engine section at the Boiler Laboratory

by the Bureau of Engineering, the scope of the organization could be broadened easily to cover Diesel fuel oil. This should be done as a second step, establishment of the organization being the initial step. As conditions warranted, slight additions to the organization would permit the transfer of all questions connected with gasoline and lubricants to be effected. The basic organization would cover all petroleum products but the present unsatisfactory condition of the bunker fuel oil situation dictates that that product should be cared for first.

The eventual result would and should be a Naval Petroleum Organization which would be properly equipped to handle every naval question regarding petroleum, its products, and their uses. These questions are now scattered between many bureaus and offices with little coordination and apparently with little absolute military direction. The matter is one for the Navy itself to handle. Full cooperation should be provided for but the matter cannot effectively be delegated to any other organization, governmental or commercial. Naval security demands coordination of all technical, economic, and military considerations of petroleum under a guiding hand which, while it recognizes the importance of the other considerations, places the military aspect above all others.

REPLY TO DISCUSSION BY LIEUT. H. A. SCHADE (C. C.) U. S. N.

By HENRY F. SCHMIDT.

First of all I wish to thank Lieutenant Schade for having pointed out a mistake which I had made in regard to the regain of kinetic energy due to the rearward component of the overboard discharge. Lieutenant Schade is absolutely right in his analysis.

With reference to the effect of the boundary layer, Lieutenant Schade makes the statement that "the condenser water is taken from the moving mass of water coming from ahead, not from outboard." Photograph Figure 1 showing the actual stream lines obtained from tests of a lipless scoop, indicates very clearly that the flow entering the scoop includes all the stream lines within a distance from the shell equal to the inlet dimensions of the scoop taken at right angles to the stream flow just as though the scoop were completed and projected beyond the hull an equal amount. An examination of the photograph also shows that the region aft of the entering stream is filled up from the region beyond the stream entering the scoop.

From experiments on the *Raleigh,* those given by G. S. Baker, and also tests by the Pitometer Company, indicate that at the usual equivalent protrusion of a lipless scoop or the protrusion of the ordinary common scoop of say 14 inches from the hull, the relative velocity of the water is 85 or 90 per cent of the ship's velocity through still water, and at about double this distance, the relative velocity is practically equal to the ship's velocity through still water. Thus, the water which fills in and comes into contact with the ship's plating from outside of the stream entering the scoop is substantially undisturbed water and this must be accelerated to the mean wake belt velocity of the water which it has replaced.

It would be unreasonable, and would not be in accordance with common experience, to assume that the process of picking up the water and replacing it is performed without losses, and consequently, one would expect the resultant resistance required to overcome the picking up and replacing of this water to be greater than the theoretical, that is, we can not expect such a process to be performed with an efficiency of 100 per cent, which Lieutenant Schade would credit it with. Also, there is a disturbance of the stream lines around the hull when the water is forced out of the overboard discharge which must necessarily cause a further loss, which, however, has not been directly included in the writer's calculations.

The loss should be 6.5 per cent instead of 9.6 per cent as given in my article if the overboard discharge makes an angle of approximately 30 degrees with the skin of the ship. There are many ships, however, which do not have scoops, employing pumps for condenser circulation and in which the overboard discharge is at right angles to the hull. For such cases it is obvious that the original calculation would still hold and this is true of many foreign high speed destroyers as well as, for example, the *Lexington* and *Saratoga*.

Lieutenant Schade's comments coincide with those of the model basin as would be indicated by the closure to the paper on "Full Scale Trials on a Destroyer," an extract of which appeared on page 131 of the February A. S. N. E. JOURNAL. The discussions of this paper and the reply appear in Volume 41, Transactions of the Society of Naval Architects and Marine Engineers. In this discussion it is stated that "Almost all of the added resistance is due to the scoops as appendages." If we were to take this statement as correct, then the lipless scoop would have almost no resistance, or from 6 to 3.4 per cent less than the common scoop, since the resistance of the common scoop at 20 knots is given as 6.1 per cent and 3.4 per cent at 34 knots.

These figures are, of course, based on attempts to measure the added resistance due to the circulating water on a model to which scoops were fitted. The writer feels it is impossible to simulate the flow conditions and measure the additional power on a model and correct this to the full size ship because of the variation in the proportion of the wake belt thickness.

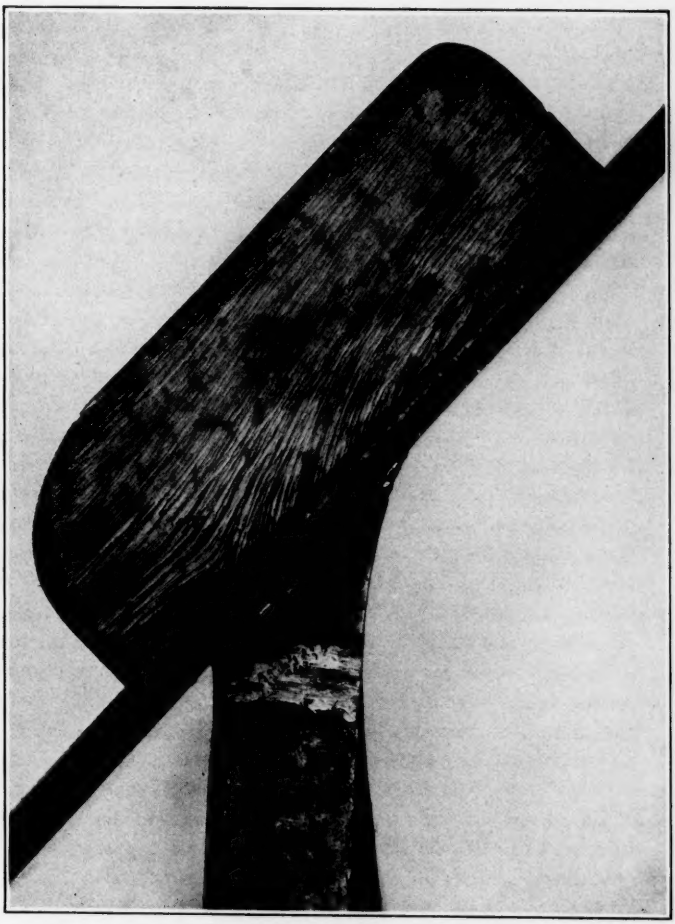

FIGURE 1.

The effect of the thicker wake belt surrounding the ship model is to prevent the filling in of undisturbed water from farther out, since the projection of the scoop or its equivalent protrusion is considerably less than half the ratio of protrusion to wake belt thickness of a full size ship. As shown by the stream lines in the photograph, the water out beyond about twice the protrusion is not much influenced by the flow into the scoop.

There is a large mass of data available for correcting the skin friction of a model to the actual ship, but this does not apply to scoops.

If the model basin considers scoop resistance only as that of an appendage, then how is the resistance of a lipless scoop and lipless overboard discharge accounted for? Also how is the resistance of a ship equipped with standard sea chests and circulating pumps to be corrected for the quantity of water circulated?

There is a method by which this could be done at the model basin, but it can not be done correctly by the present methods.

The results obtained from scoops on actual ships as well as model scoop tests show that the quantity of water passing through the scoop is directly proportional to the speed of the water relative to the scoop entrance, which in turn is directly proportional to the ship's velocity through still water; and since the head has been found to vary directly as the square of the speed, the power varies as the speed cubed. Therefore, it is difficult to understand the percentage proportion of power loss as falling off nearly as much as indicated by the model basin test; that is, the percentage of scoop resistance should remain constant at all speeds except for the small amount by which the E.H.P. departs from the cube relationship. This was very small in the case of the U.S.S. *Hamilton,* between 20 and 34 knots according to the published data.

As for the quantity of water passing through the condenser, this can be determined with about the same degree of accuracy as the ship's resistance, since the quantity of steam entering the condenser is known, it's quality is approximately known, and the quantity of water passing through the condenser can be calculated from the temperature rise of the circulating water. These records are available on quite a large number of naval vessels so that there is no difficulty in determining the quantity "Q" in the formula.

DISCUSSION OF LIEUT. COMDR. REDFIELD'S PAPER ON "PARALLEL OPERATION OF SINGLE STAGE BOILER FEED PUMPS."

By A. PETERSON.*

The present and also the future Navy Program requires a considerable number of high speed turbine driven boiler feed pumps, which makes the article entitled "Parallel Operation of Single Stage Boiler Feed Pumps" by Commander H. J. Redfield in the November 1933 issue of the JOURNAL quite timely and also of considerable interest.

The article, however, contains certain statements and also certain conclusions may be drawn from it with which I do not agree.

The title of the article implies that as far as parallel operation goes the single stage boiler feed pump is in a class by itself and this is further borne out by the following statement appearing in the article:

"With few exceptions the leading manufacturers of this type of unit both in this country and abroad held that it was impossible to parallel single stage pumps and that they were regarded as single purpose units not suitable for parallel operation."

Pump manufacturers who stated that it was impossible to operate single stage boiler feed pumps in parallel could not have had much experience in building high-pressure high-speed centrifugal pumps.

No greater difficulties are involved in operating two single stage boiler feed pumps in parallel than there are in operating two 2-stage or multistage pumps in parallel; in fact, it is entirely feasible to operate a single stage boiler feed pump in parallel with a 2-stage pump, and this applies both to constant speed operation and to constant discharge pressure or constant excess pressure operation.

It is, however, somewhat more difficult to design high pressure pumps either single stage or multistage type for satisfactory oper-

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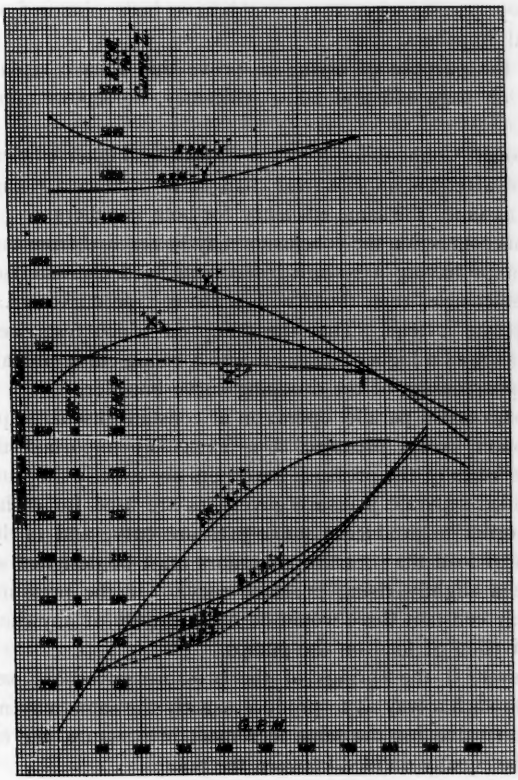
ation in parallel at constant speed because the shape of the head characteristic curve then becomes more important.

With properly designed pressure governors there should be no difficulty in operating any type of pumps in parallel irrespective of shape of characteristic curves.

Most pump manufacturers have known for years that it is absolutely impossible to operate two centrifugal pumps in parallel at *constant speed* if the shape of the head capacity curve is as indicated by X on page 455 of Commander Redfield's article.



Parallel operation at constant speed with this pump is only possible down to a capacity of about 400 G.P.M.; below this capacity the curve is unstable and parallel operation is impossible. Most pump manufacturers could have predicted this before attempting parallel operation.

Commander Redfield's article does not state definitely whether or not parallel operation was attempted with pressure governors before the impellers were changed to produce head characteristic curve marked Y.

With properly designed pressure governors I maintain that satisfactory parallel operation would have been obtained with the original impellers.

For the purpose of trying to prove this I have replotted the curves on page 455 and added efficiency, horsepower and speed curves.

Although Commander Redfield states that higher efficiency was obtained after the impeller was changed to produce a rising curve, I have assumed the same efficiency for both impellers.

In this connection the conclusion may be reached from the article that pumps having a so-called drooping head characteristic have lower efficiencies than those with a rising type curve. As a rule the opposite is true. That the pump on which tests were conducted showed a higher efficiency with a rising curve probably was due to poor design of the drooping curve impeller.

For successful parallel operation at constant discharge pressure or constant excess pressure, it is extremely important that the characteristics of the pressure governors are exactly the same, that is provided separate pressure governors are used for each pump, and in order to produce a stable pressure curve and fairly equal division of load the pressure governors must be designed so as to produce a slightly rising pressure curve. If the pressure were absolutely constant there would be no assurance of anywhere near equal division of load on the pumps.

However, if the springs of the pressure governors were designed in such a way as to produce exactly the same movement of the steam valve for the same increment in pressure, the capacity should be equally divided between the pumps.

When two or three pumps are operating in parallel the discharge pressure produced by each pump must necessarily be the same. Now, if the feed water regulator at the boiler should be closed slightly thus introducing greater friction through the regulator, which in turn diminishes the capacity, the load on the turbines is immediately reduced and this in turn causes an increase in speed and also in pressure, the pressure increasing as the square of the speed increase, and this in turn transmits itself to the diaphragm or piston of the pressure governor, causing the steam governor valve to throttle so as to produce substantially the same pump pressure, giving the valve a new setting corresponding to the load required at the reduced capacity of the pump.

The shape of the constant speed head capacity curve therefore does not enter into the successful parallel operation with pressure governors because the impulse on the piston or diaphragm of the pressure governor is produced by an increase in speed, resulting in increased pressure rather than due to the natural shape of the head capacity curve.

The standard Navy specifications for boiler feed pumps require a rising head capacity curve with a shut-off pressure 50 pounds higher than normal rated head. This is also in accordance with the last paragraph of Commander Redfield's article. I maintain that for constant pressure or constant excess pressure operation this requirement is entirely unnecessary and of no advantage for parallel operation.

As may be noted from the speed curves, which indicate the speeds required to produce pressure curve Z both with the drooping and rising curve, less speed reduction from normal is required with the drooping curve and consequently the turbine efficiency will be somewhat higher than is the case with the rising curve.

Further, it is as a rule possible to obtain higher pump efficiency by the use of a drooping head characteristic.

Therefore, if the Navy specifications were amended to state that turbine driven boiler feed pumps must be designed so as to operate satisfactorily in parallel without any reference to shape of head capacity curve, the Navy would be assured to obtain just as satisfactory and more efficient pumps.

Common practice has been to connect the steam and water side of the excess pressure governor diaphragm or piston to the steam line near the turbine and at the discharge nozzle of the pump. This is not conducive to the best possible operating efficiency. The point where constant excess pressure should be maintained is not at the pump but near the boiler across the feed water regulator. By maintaining a constant excess pressure at that point considerably lower excess pressure is as a rule required than if connections are made at the pump. The reason for this is that there is always a certain amount of friction loss in the discharge line from the pump particularly if there are heaters or economizers in the line and there may also be considerable friction losses in the steam piping and through the superheater, all of which means that at reduced pump capacities considerably greater excess pressures than required would be obtained if the connections to the excess pressure governor were made at or near the unit.

Considerable savings in power and steam are thus often possible by holding a constant excess pressure across the feed water regulator. In that case the discharge pressure curve of the pump would be drooping all the way towards shut-off pressure which, however, does not preclude satisfactory operation in parallel provided the excess pressure governor is designed to maintain a rising excess pressure across the feed water regulator.

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COAL V. OIL FOR THE NAVY.*

By Engineer Vice-Admiral Sir Reginald W. Skelton.

INTRODUCTION.

Coal *versus* oil fuel for the Navy—the subject on which I am privileged to address you this afternoon, has, as a matter of fact, ceased to exist for some years as a controversial question for the responsible authorities, at any rate since the Great War.

It can also be said that all thinking naval executive and engineer officers and naval architects are agreed that the fuel of today must be liquid; but since this country does not, unfortunately, possess within these islands any known appreciable source of natural oil, but does possess large quantities of the best steam-raising coal, it is quite natural that those people who earn their livelihood from coal should be bitterly disappointed that their fuel cannot now be made use of in the British Navy, and that, misled by the less responsible publicists and supported by even less reputable facts and data, they should from time to time question Naval policy and plead for sympathy.

You will gather from these opening remarks that I am myself in no doubt whatever as to which is the proper fuel to be used today.

I have seen it argued that the present generation of naval officers is not responsible for the use of oil fuel; that is quite true, but the aim of that statement was to show that some distinguished naval officer—or politician—(names were actually mentioned) drawn into the spider's web of some oil magnate, had combined with Machiavellian cunning to force this unwanted foreign product on the British Navy.

It is hardly worth while discussing such suggestions; the truth is, of course, that you cannot stop the march of progress, and the fact is that no single individual or even a small coterie of individuals has been responsible for the introduction of oil fuel for the Navy.

Its technical development and use has, under successive Engineers-in-Chief of the Fleet, and one might say the whole naval engineering personnel at sea, proceeded from day to day; the technique being assured, the approval for its adoption has, in all the circumstances to be considered, been made, not by one man, but successively by a host of men in the governing positions.

These developments are evolutionary; they can be delayed, they can be hastened; but if good and right, their preponderating advantages must lead inevitably to their increasing use.

About 1908, destroyer programs with oil fuel alone having progressed perhaps somewhat quickly, some doubt was felt about the certainty of supply, and it was decided that the *Beagle* class of twenty T.B.D.'s, then being designed, should use coal. The disadvantages of coal, already well known in the technical departments, soon became apparent to all, and in the very next program coal was finally abandoned for the *Acorn* class, oil restored, and this has continued ever since. Coal lasted in the destroyers one program only, after oil had once been tried—one year's batch—and the following comparison shows the reason.

Acorn, as compared with *Beagle*, had a superior armament—20 per cent less displacement, cost 16 per cent less, and was 1½ knots faster and could hold her speed until fuel ran out.

Since that date the developments in T.B.D.'s with oil fuel have far outstripped those mentioned as a comparison between *Beagle* and *Acorn*.

* Royal United Service Institution, Wednesday, March 14, 1934, at 3 P. M.

It seems the Admiralty were all the time from 1903 onwards tending towards 100 per cent use of oil fuel in the Navy, and yet it is 1931 before a petition is engineered for a return to coal. Was King Coal asleep?

But after all it must not be supposed that the experiments and improvements in the burning of oil fuel made at Haslar and in the Fleet were confined to oil alone. Mechanical stokers had been tried, and all the advancements in the handling and burning of coal by the mercantile marine and in shore power stations have always been, and are being, watched to see if any of them could be applied with benefit in H.M. ships.

TECHNICAL.

The calorific value of oil fuel is about 1.3 to 1.4 times that of coal. As measured in British thermal units, oil is about 19,000, while best Welsh steam coal is about 14,500.

But while oil is fairly uniform in quality, whatever its geographical origin, while it does not deteriorate with storage, nor does it contain ash, coal is not uniform, not even Welsh, while the variations in coal from the various sources of origin over the world are enormous. Coal does deteriorate slightly with storage; it becomes dusty with handling, and contains an objectionable amount of ash, though these disadvantages can be mitigated by modern methods of washing and handling.

The space required for stowing 1 ton of Welsh coal is 40 to 43 cubic feet, whereas 1 ton of oil fuel averages about 38 cubic feet; moreover, oil bunkers can be safely filled to 95 per cent full stowage, whereas in coal bunkers there is an appreciable loss from broken stowage, sufficient space having to be allowed under the beams at the crown of the bunkers to provide for ventilation and to permit egress of coal trimmers.

PULVERIZED FUEL AND MIXTURES.

I will make a short digression here to mention pulverized fuel and mixtures of pulverized fuel and oil. Pulverized fuel cannot be carried in bulk; it is dangerous; but even if it could, it would have to be kept "fluffed," i.e., prevented from packing, and in that condition requires much more space—55 to 60 cubic feet per ton. Alternatively, if the coal is pulverized as it is required for use, on the "hand-to-mouth" system, then much additional machinery, absorbing space and weight, must be installed to do the work.

Mixtures of pulverized fuel and oil, erroneously called "colloidal fuel," have been tried for many years, and while increased weights of this fuel per cubic foot of space over oil alone can be stowed, no mixtures so far tried have proved really stable or suitable for stowage in and use from warship tanks.

STOWAGE.

Oil can be stowed in any compartment, large or small, within reason, in ships, no matter what shape or where situated; contiguity to the boilers is not necessary, and the fullest use of every such space throughout the ship to each and all of the boilers can be made without impairment of supply.

TRANSPORT TO BOILERS.

In coal-burning ships the only readily accessible stowage is above the floor plates and abreast the boiler-rooms, and in ships requiring much endurance a large proportion of the coal must be stowed in bunkers which

are not easily accessible or which cannot be worked without increasing the labor necessary to keep up and maintain supply. In the war, for example, many ships carried large quantities of coal in reserve bunkers which it was found impossible to use, and for operational purposes had no value whatever, and under no circumstances could such coal be transported to satisfy any other rate for steaming but a low rate.

To supply coal from bunkers to boiler-rooms a number of water-tight doors must be fitted in the bulkheads, scuttles and armored doors in the protective decks, making for weakness and expense in construction and vulnerability under working conditions at sea. With oil fuel these doors, scuttles, etc., are not required, and the water-tight sub-division is therefore more efficient, the protection is thereby improved, and the strength of the structure increased. Moreover, the bulkheads, decks, etc., forming the boundaries of the fuel tanks remain fully efficient, being always under test, a condition which cannot be assured with the boundaries of coal bunkers. In the latest warships, in which the weight of fuel carried reaches 30 per cent of the displacement, this advantage is most valuable.

GENERAL EFFECT ON DESIGN OF SHIPS.

It is almost impossible to design a warship providing for anything approaching an equal supply of coal to each group of boilers, and still more difficult to ensure this state of affairs at the commencement of an action. I may mention my own ship, H.M.S. *Agincourt*, as a particularly glaring example, although in fairness it must be said that the ship was not Admiralty designed. She had three boiler-rooms, A, B, C. A had 450 tons of coal abreast it, B had about 800 tons, and C, including reserve bunkers, about 2000 tons (my figures are, at this distance of time, approximate). If it had not been possible to carry 600 tons of oil fuel in the double bottoms, and if we had not converted the boilers to take Admiralty oil fuel fittings during the first six month of the war, while remaining at sea, that ship could never have remained in the line, after a few days out of harbor at high speed, with battleships of contemporary Admiralty design; and the anxiety of the chief engineer and the captain of such a ship, as to whether the fuel could be brought to the furnaces to satisfy all conditions of steaming, is not such as one who has experienced it will easily forget.

It might be argued by the technical protagonists of coal (if there are any such people—I have yet to discover them) that modern coal-handling machinery could be devised to bring coal from any part of the ship to the fires, without requiring trimmers; perhaps it could, but how to do so without putting impossible encumbrances on the naval architect, impairing the water-tight sub-division of the ship, and introducing heavy and complicated machinery to go wrong at any moment in action, is quite beyond my own vision.

PROTECTION.

It has been claimed that coal bunkers provide protection against enemy action, which oil bunkers do not, and the case of a torpedo hitting H.M.S. *Marlborough* at Jutland is quoted as the classical example. As a matter of fact, that torpedo expended most of its energy on a Diesel engine electric generator (much to the gratification of the engineer commander, who got a new and better one), and the saving of the ship by coal bunkers is simply not the truth. But in any case the claim as to coal bunkers is largely fictitious.

It is necessary, for reasons I have already shown, to trim down coal from the upper bunkers as soon as possible after leaving harbor to ensure an adequate supply in the immediate vicinity of the boiler-rooms for action, and the

supposed protection afforded by the coal will probably be lost by the time contact with the enemy has been established. It might even be the case that at the critical moment a bunker door might be open and jammed with coal.

FUELING SHIP.

Another advantage, arising from the same fact, is in fueling ships. Fittings required for refueling are merely pipes, filters, and valves, and involve much less disturbance to the hull structure than those required for coaling. The rates of refueling can be considered as two to three times the rate of coaling, and that with practically no effort on the part of the personnel. Ships can also be stored and ammunition embarked at the same time. As soon as these operations are performed the ship is ready for sea, without having to be cleaned and without a fatigued personnel.

GENERAL EFFECTS ON DESIGN OF MACHINERY.

In the design of the machinery no actual advantage accrues to the main propelling steam turbines from the use of oil fuel, but when we come to the boilers and boiler-rooms the advantages are most marked. The human element sets a limit to the size of fire-grate which can be adopted, since, if the length of the grate is increased beyond about 7 feet 6 inches, the fires cannot be efficiently served and cleaned. The length of oil-fired boilers is only limited by the consideration of ensuring that the particles of oil and air necessary for its combustion can reach the extreme end of the combustion chamber. Modern oil-fired boilers can be made up to a length of 20 feet and more, if necessary. For high-powered ships, therefore, the use of coal involves a large number of small boilers, whereas with oil the same output can be obtained from a small number of large units, an arrangement which results in a considerable saving in the weight and space required for the machinery. It also permits of a more favorable water-tight sub-division of the hull with consequent improvement in immunity from under-water attack, both to hull and machinery.

Coal-fired boilers necessitate the installation of machinery and gear for getting rid of ashes; they require relatively more fan engine power, and the general effect on machinery design is to add greatly to the weight and space required.

MANNING.

The engine-room complement of a large ship is decided chiefly by the number of men required to steam the ship continuously at high power, working in three watches, and it follows that this complement for a large coal-fired ship is from three to four times that of an oil-fired ship power for power; for example, H.M.S. *Tiger*, 108,000 S.H.P., coal and oil, E.R. complement 600; H.M.S. *Hood*, 144,000 S.H.P., oil only, E.R. complement 300. In a modern 8-inch gun cruiser as increase of at least 250 men on existing complement would be required.

Supposing for the moment that it was possible to convert the Navy as it exists to-day to an all-coal one, an addition of the order of 15,000 men would be required.

OPERATIONAL.

Oil fuel ships can steam continuously at maximum power, say, 90 per cent to 100 per cent, until all the fuel on board, wherever stowed, is expended, without any noticeably increased effort on the part of the personnel. There

is little fouling of the combustion spaces in the boilers, no fires to be cleaned, no ashes to be drawn and pushed overboard, and there are no calls made for deck assistance.

As between the two fuels, and with the latest improvements, combustion with oil almost attains that theoretically possible and is under perfect control all the time. With coal the limitations are most serious; one has only to read the Admiralty regulations in the "Steam Manual" of the all-coal-fired-ship days to realize this. A full-power trial then consisted of eight hours at 100 per cent F.P. with sixteen hours at 60 per cent. Sixty per cent was the maximum power obtainable until the coal was finished, and speaking from considerable experience, it can be said that even this low percentage of power depended very largely on the organization, the skill, and endurance of the engineering personnel, and with, in many cases, frequent calls for deck assistance to bring the coal in distant bunkers to the vicinity of the various stokeholds.

Is this enormous handicap and all that follows from it in the qualities of the ship to be lightly accepted? I know of no naval engineer officer who has experienced service under both conditions who would think twice about the matter.

SUPPLY.

I come now to an important question which, I believe, really forms the basis of all arguments and of all agitation against oil, and that is the question of supply.

It is contended that while our supplies of oil could all be cut off at source, the supplies of home-produced fuel are always available. Putting aside for the moment those cranks who will not listen at all to any of the reasoned arguments on the coal versus oil question, it is quite natural that many naval officers, retired, and others deeply concerned for the Navy and the safety of this Empire, must say to themselves: can we keep going under all the possible circumstances of war and the requirements for the adequate defence of the Empire?

The whole question of oil versus coal in the matter of supply is most involved, because modern transport of almost all kinds and all the three services, Navy, Army, and Air Force, depend on adequate supplies of liquid fuel.

It is beyond the purpose of this lecture to introduce the matter of the possibility of home-produced liquid fuels. It would be a most serious impeachment of our controlling authorities—and that includes others besides the Board of Admiralty—if they had not been the very first to realize the importance of this question and to make a proper provision. It may well be that risks have been taken, and yet those risks have received careful and proper discussion and have been found in all the circumstances to be justifiable.

It is quite obvious that none of us here knows quite enough to discuss the matter properly. I certainly do not pretend to myself; nor, I imagine, would it be altogether in the public interest to give all the facts in connection with arrangements for supply of oil in war. But this at least can be said: we are not dependent entirely on supplies from any one country or from any one part of the world, and it is as ridiculous to say that our supply of oil is liable to be cut off at its source at any time without a shot being fired to defend it, as to say the same of any other raw materials, such as food.

Reserves of oil can be and, I have no doubt, are being built up as the responsible authorities may judge necessary. In some respects it is easier to build up reserves of oil at distant fueling bases than it is to build up reserves

of coal, a fuel much more liable to deterioration and much more of which for the same performance would be required; over 40 per cent more tonnage is required to carry the same useful quantity of coal than for oil; in point of fact the position is far worse than that, because oil can be carried in the double bottoms and tanks other than bunkers, and in those of ships other than pure colliers or oilers.

Another point that is often forgotten is that there can be no certainty or, I hope, probability that future wars will be fought entirely in home waters, and quite apart from the difficulties of transport mentioned above, there can be little doubt that in most parts of the world it is now easier to get oil fuel than good Welsh coal.

The one disadvantage of having to transport oil in large quantities to these islands is fully recognized, and without exception everybody concerned would much prefer to use a home-produced fuel, were it possible to do so.

Briefly and to summarize, the advantages obtained from the use of oil are:—

Increased endurance for a given weight of fuel approximately up to the ratio of 2 to 1.

Longer periods at sea without having to return to harbor.

Increased power and speed for a given weight of machinery.

Alternately, equal power can be obtained on a reduced weight and space of machinery, permitting the difference in weight and space to be devoted to other military requirements, viz., armor protection, armament, etc.

Increased flexibility.

Reduced complement.

Short time required in harbor to replenish with fuel and stores, and ability to go to sea at once without a fatigued personnel.

Full power can be maintained as long as fuel lasts instead of only 60 per cent.

Absence of smoke and ability to control smoke for tactical purposes.

Transfer of fuel for correction of heel and trim in event of damage.

Transport to distant fueling stations more easy and less of it required in store.

No deterioration in storage.

In conclusion it can be stated that on a limited displacement it would be impossible to design a coal-burning ship having the same military characteristics as a ship burning oil.—"The Engineer," March 23, 1934.

STEAM-TURBINE VIBRATIONS.

Of the numerous factors requiring consideration during the preparation of any form of power scheme, that of reliability is of primary importance. It is obviously useless to introduce methods of decreasing the cost of power if the possibility of a breakdown of the entire plant is increased in direct proportion.

In the case of steam turbines for land or marine purposes, reliability is an absolute essential. The high peripheral speeds now employed, with consequently increased loading of individual parts, necessitate the careful scrutiny of each detail in regard to material, stressing and workmanship; and when a compromise has to be made between the requirements of efficiency and reliability, the decision must be in favor of the latter.

In order to obtain maximum turbine output at minimum first cost, the tendency in recent years has been to load machines to the limit; and this has

rendered necessary the solution of several problems, such as the maintenance of an adequate factor of safety in the last row of moving blades, etc. The phenomena associated with turbine vibrations have also been given more attention in the last few years; and, although turbine designers in general have of necessity gone into the question very thoroughly, one frequently meets turbine users whose ideas on the subject are not so clearly defined.

On turning to a consideration of fundamentals, it will be found that vibrations may be broadly classed as natural and forced. A simple pendulum, for instance, on being displaced from its central position will oscillate or vibrate naturally until brought to rest by various damping forces. During motion, its total store of energy is kinetic and/or potential. At the end of each swing the energy is wholly potential, whereas in the lowest, central position of the pendulum the energy is entirely kinetic. At any point during the oscillation of the bob, its total store of energy is constant. While vibrating, the pendulum has a definite frequency; and if an impulsive force with a slightly different frequency is applied to it, the result will be an acceleration of the motion of the pendulum for a certain time, followed by a retardation when the impulsive force is out of phase with the natural vibrations.

When, however, the impulses of the external force exactly coincide with the oscillations of the pendulum, the store of energy contained in the latter will be increased during each vibration, and the motion will continue until the external force is removed or breakage of the pendulum occurs. In conditions such as described, the pendulum is in a state of forced vibration, and the frequency of the external impulses synchronizes with the natural frequency of the moving bob.

Unless suitable precautions are taken during the design stage, a similar condition is liable to arise in steam-turbine work. A turbine shaft, for instance, has a natural period of vibration, as in the case of the pendulum, and may be caused to vibrate transversely by the application of a force with a frequency equal to the natural. The general result of this force is alternately to stretch and compress the fibers of the shaft.

Similarly, when a turbine shaft is at rest its weight causes it to sag slightly, so that when rotation occurs the center-line of the shaft does not exactly coincide with its axis of rotation. Centrifugal force tends to increase the deflection and bending moment acting on the shaft, and is resisted only by the elastic properties of the material. It is easy to realize that a point will be reached when the force on the shaft exceeds the internal resistance of the material, after which fracture is only a matter of time. The point at which this unstable running begins is termed the critical speed of the shaft, and, generally speaking, it corresponds to the natural frequency of vibration of the shaft.

The necessity for proportioning a turbine shaft so that its natural speed of vibration is well removed from the ordinary running speed is therefore plain, and in all but small machines a margin of safety of at least 30 per cent is always allowed.

The critical speed of a turbine shaft depends, among other factors, on the distance between its points of support, and any variation of this under working conditions results in the raising or lowering of the critical frequency. The former is preferable in the case of a turbine rotating below the critical point. In some designs—as, for instance, a tandem compound machine with a solid coupling between the high-pressure and low-pressure end bearings—incorrect lubricating conditions may set up considerable wear in the high-pressure turbine bearing. In this event the tendency will be for the low-pressure turbine bearing to carry all the load, and under extreme conditions the effective span of the shaft will be increased by some 12 to 18 inches. The

margin of safety between the running and critical speeds will thus be reduced, and heavy vibration, if not a serious accident, will ensue.

A misaligned turbine shaft may give rise to a similar effect, while other contributory causes are to be found in badly balanced or bent shafts. In the case of impulse turbines and certain designs of reaction machines, there is the danger that this state of vibration may be transmitted to the discs mounted on the shaft.

For a considerable period during the development of the steam turbine the subject of disc vibration was not given a great deal of attention, and it was only on the incidence of a series of breakdowns due to disc failure that turbine designers began to take a serious interest in the subject. There are several cases on record in which discs have been fractured through vibration-fatigue stresses, and it is probable that a large number of blading failures originate in disc vibrations.

The simplest and most uncommon form of disc vibration occurs when a turbine coupling or adjusting block gives rise to axial vibrations in the rotor shaft. This tends, so to speak, to turn the disc inside out, umbrella-fashion, and is consequently known by that designation. Another cause which is likely to set up an umbrella vibration is the ejector action of the steam in impulse-turbine stages with full circumferential admission. When there is a pressure difference between the two sides of a disc, as when the balancing holes are on the small side, a force tending to produce an umbrella movement on the disc is set up. The disc is deflected from hub to rim, the deflection varying on each side of a central position, according to the direction of the pressure difference. A similar action occurs when the disc vibrates about a nodal circle, but neither of these types of vibration is likely to cause severe stresses.

The most dangerous form of disc vibration is that which takes place about one or more nodal diameters, and several breakages have been definitely traced to this source. Vibration may arise from causes such as partial circumferential admission, and becomes evident when the frequency of the steam impulses synchronizes with the natural frequency of the disc. The number of nodes about which vibration occurs depends on the strength of the disc. A very weak disc will vibrate about five or more diameters, while one that is just below the requisite strength will vibrate on only two or three nodal diameters. During working conditions there may be a temperature difference between the thin rim and its comparatively thick body and hub, and this effect has an important influence on vibration. When the rim is cooler than the disc body, the frequency of vibration of the discs as a whole is increased; whereas when the rim is at a higher temperature, the frequency is reduced. A change of turbine load, therefore, may result in severe vibration, as the temperature difference may be such that the disc-frequency figure may fall to that corresponding to the steam or similar impulses.

Considering a disc of which the natural frequency corresponds to that of the turbine impulses, then when vibrating at N revolutions per minute about D nodal diameters, the disc will have a frequency of DN. The frequency of the disc increases with the number of nodal diameters about which it vibrates, and by plotting disc and exciting-force frequencies against nodal diameters it is possible to determine whether a given disc will vibrate under working conditions or not. The curve of the exciting impulses is a straight line, and as long as the disc frequency curve is above this line synchronization cannot take place. When the disc curve lies below the other line, it may cut it at a whole number of nodal diameters, in which case synchronization is inevitable.

A disc for a given turbine, therefore, may be designed so that its characteristic curve lies well above the line of probable impulses. This implies

the provision of a stiff, and consequently a more expensive, disc; but the possibility of vibration occurring at ordinary running speeds is eliminated. As an alternative, a disc may be designed so that the straight line of probable impulses cuts its characteristic at two critical points, the working condition being between the two points. This permits the use of a ligher disc, but a slight vibration will occur when running up to speed; and any serious variation of the designed revolutions per minute, or the introduction of unforeseen forces, may result in heavy vibration.

The effect of centrifugal force on disc vibration, as might be expected, is to raise the frequency of vibration. Generally, a disc rotating at high speed is not so susceptible to vibratory influences, and, if strong enough to withstand centrifugal stresses, will be free from the risk of vibration. In the case of a large-diameter disc working at a comparatively low speed, however, the possibility of vibration must be given careful consideration, and centrifugal stresses are of less account.

The blades attached to a disc tend to lower the frequency of the latter, thus bringing it nearer to the running impulses. The blading itself is also liable to vibrate under certain conditions, the resulting fatigue being the cause of many failures in practice. Long blades are more likely to suffer from this than short ones, but the vibration may be minimized, or even eliminated, by a suitable grouping of the blades. The method of securing the blade root to its disc is of great importance and should be as rigid as possible; while the provision of binding and shrouding strips, etc., has a beneficial stiffening effect. In all doubtful cases the periodicity of the blades is determined either graphically or by experiment. The latter is perhaps the better method, and some turbine makers use a testing apparatus in which the blade oscillations are measured by means of alternating valves.

In addition to vibrations originating in the turbine shaft, discs and blading, several subsidiary but nevertheless important causes must be taken into consideration. Some of these may be classed as temperature effects, and may be minimized by careful design and operation. In warming through a turbine, for instance, it is possible to set up a temperature difference along the turbine shaft so that the latter tends to contract or expand out of truth. When this is repeated several times, a permanently bent shaft results, which may set up a more or less serious vibration when at speed. It is important therefore, that when a steam turbine is warmed through "standing," as in the case of marine sets, the rotors should be turned at frequent intervals.

A badly designed cylinder may give rise to a similar effect on being heated, especially when the ribbing, etc., is located so that the gland or dummy strips are likely to touch the shaft because of the resultant distortion. Heavy steam pipes with an insufficient allowance for expansion are another source of distortion vibration, and have been the cause of several minor turbine troubles.

The importance of eliminating as far as possible all out-of-balance forces in a turbine rotor is fully appreciated, but even the most perfectly balanced turbine may vibrate under working conditions if proper attention is not given to the boilers. Boiler priming is a phenomenon which has been investigated by a number of authorities, but it still obtains in some steam installations, with a detrimental effect on turbine performance. The low-pressure moving blades appear to be the most affected; and the sediment carried over with the steam often lodges in between the blades at the shrouding, throws the entire rotor out of balance, and sets up severe vibration. The only real remedy for this would appear to be the prevention of priming, as steam strainers have very little effect.—"The Shipbuilder and Marine Engine-Builder," March, 1934.

IMMERSION OF PROPELLERS.

Three years ago Rear-Admiral Taylor read a paper before the North-East Coast Institution of Engineers and Shipbuilders entitled "Variation of Efficiency of Propulsion with Variation of Propeller Diameter and Revolutions." This dealt with a series of experiments which had been made in connection with the propulsion of a single-screw vessel 400 feet in length, 56.5 feet in breadth and 22.6 feet in draught. The form was that of Mr. Baker's model No. 56e, which was found to be most efficient. Admiral Taylor's scheme of experiments was to find the effect of size of screw and also the effect of number of revolutions on the propulsion of a single-screw ship. For a speed of 14 knots he aimed at obtaining self propulsion at 60, 80, 100 and 120 revolutions. Under each of these conditions three separate screws, varying in diameter and pitch, were tried, so that in all he had 12 different propellers in his series. From the results obtained it was shown that the number of revolutions had a remarkably small effect on the propulsive efficiency, that is, within the range of his experiments. Admiral Taylor remarked, "the efficiency curves are superficially encouraging to advocates of small propellers and high revolutions. They show, however, that beyond a certain point increase in revolutions is necessarily accompanied by loss of efficiency be the propellers small or large." Dr. Kempf, in his paper read last week to the members of the same Institution, dealt with the same general subject. He has extended the scheme introduced by Admiral Taylor. The latter's experiments were carried out at one draught only. Dr. Kempf has continued for the same model, with three of the best propellers of different diameters, for five different draughts of the ship, and accordingly for five different immersions of these propellers from loaded to light condition.

Although the results obtained in the Hamburg Tank differ from those obtained at Washington, there is only very slight disagreement; for all practical purposes it may be said that Admiral Taylor's figures have been verified. If anything, the higher running screws do not show up quite so well, but the variations between the results are small, as the following figures in the paper indicate.

PROPULSIVE EFFICIENCY RESULTS AT 15 KNOTS.

Revolutions	*Washington* *Per Cent*	*Hamburg* *Per Cent*
60	76.	77.8
70	76.6	77.3
80	77.5	76.8
90	77.6	76.3
100	77.3	75.8
110	77	75.3

Considering that the screws were made in different establishments and that the gears employed were dissimilar, the agreement in results is remarkable.

It appears from the above that a much wider field is open for efficient propulsion than was at one time thought to be the case. In the days of the universal application of the reciprocating engine, low revolutions were considered necessary. The introduction of the internal-combustion engine with from 110 to 115 revolutions, caused some fears to arise regarding reasonably efficient propulsion, but actual experience showed these fears to be groundless. Admiral Taylor showed that the wake gain is considerably improved with the smaller, fast-running propellers, and this offsets

the loss which is indicated by propeller charts due to the adoption of high revolutions. On Figure 9 in Dr. Kempf's paper, values of wake are shown. From these curves, assuming that the S.H.P. delivered by the engine is constant, it is seen that the wake increases from the deep draught to the mid draught from 0.24 to 0.315, and from the mid draught to the light draught from 0.315 to 0.335. Dr. Kempf remarks that the Admiralty constants for the draughts from the deepest to the second lightest differ no more than 5 per cent.

Care must be taken in the interpretation of the values given by Dr. Kempf to remember that the form experimented upon was relatively fine. A block coefficient of 0.65 is not frequently applied to single-screw ships, and it is likely that much wider variations in wake and in Admiralty constants would be shown by full models of usual single-screw cargo-ship type. Some extraordinarily high wake values have been disclosed in experiments with full models at light draughts, and some very poor Admiralty constants obtained by vessels running under light draught conditions. On the one hand, the high wake values would suggest efficient propulsion; on the other, it appears that the lack of immersion told against the efficiency of the screws.

In connection with the latter aspect of the problem Figure 11 in Dr. Kempf's paper gives the results of open-water tests with a propeller at different immersion ratios. These show relatively small variations in efficiencies at the same actual slip, but very decided variations in the thrust and torque coefficients. When the appropriate torque coefficient is applied for the absorption of the available shaft horsepower (assumed in this particular case to be 3200), the differences in propeller efficiencies become much more drastic and such differences may well account for the cases of inefficient propulsion at light draughts which have been observed.

Accordingly, while it may be argued that advantages lie with the adoption of reasonably large propellers, with the adoption of slower-running machinery, from the point of view of maintenance of speed in rough weather, it appears that smaller propellers with high-running machinery offer reasonably good efficiencies in calm and moderate weather and fit better the variations in draught under which a vessel may operate. In this connection, actual experience should afford shipowners definite guidance as to the desirable dimensions and revolutions of screws. The paper given by Dr. Kempf is of much value and great interest. It suggests, however, that the case of a fuller cargo vessel of about 0.75 block coefficient should be considered, for such would have greater applicability to average conditions than the fine form which has been chosen for these particular investigations. —"Shipbuilding and Shipping Record," March 8, 1934.

BRITAIN'S AIR POLICY.

The Government's air policy, as outlined in the debate on the Air Estimates in the House of Commons on Thursday, March 8th, may be characterized as one of tentative compromise. For ten years the present Cabinet and its predecessors have labored to secure aerial disarmament or limitations, and as a contribution to the attainment of that end Britain's aerial strength has been cut down, and kept down to a low numerical level. The effort, well worth the making, has unfortunately proved of no avail. All the other principal Powers have shown a practical disinclination to reduce their air power, and, for the most part, have added, and are planning still further to add, very

considerably to their strength. The gravity of the situation in which this country had been placed, or had placed itself, was fully recognized and acknowledged by the Government at the end of last November. It was announced then that while attempts to secure eventual agreement would not be abandoned, steps would be taken to place Great Britain on a footing of equality with any other country within aerial range of her shores. If other nations would not come down to our level, we would secure parity by building up to theirs. It was immediately obvious that this declaration of policy on the part of our Government created a situation of considerable delicacy. Any precipitate action taken to implement it might readily have initiated an international aerial armaments competition, an outcome directly opposed to our intentions and desires, and, almost certainly, of incalculable harm to the cause of peace. Further, it was scarcely possible to present to the world a policy designed solely to give us security against aerial aggression without admitting the justice of Germany's case for the revision of the aerial clauses of the Versailles Peace Treaty in a manner that would give her similar security. The Government's plans for the immediate future have now been revealed. For the first time for several years the gross expenditure on the Air Service is to be increased instead of decreased, the increase being £527,000. Four new squadrons are to be provided, of which two will be allocated to home defense, one will be composed of flying boats—presumably for coast patrol and anti-submarine duties—and one will form an addition to the Fleet Air Arm. Further, two squadrons at present forming part of an experimental establishment are to be reconstituted as home defense squadrons.

Omitting the flying boats and naval machines, our home defense strength is at the most to be increased by four squadrons, or, say, by forty to fifty effective machines. It can hardly be asserted that such an increase is provocative. It will still leave us fifth—or sixth—in the order of the world's air Powers, and will result in raising only to about 900 the total number of first-line machines at the disposal of the Air Ministry for undertaking all the aerial work with which it is charged at home and overseas. For strictly home defense purposes it will increase our strength to about 540 machines, or, say, ten per million of the population. This addition to our aerial strength is too modest to be a menace to any other nation, and is admittedly only a small contribution towards fulfilling the Government's expressed intention of securing parity with the strongest aerial Power within striking distance. It is obviously meant to be a gesture, a sign of the sincerity of the avowal to obtain equality by one means or another, and an indication of our future course should other nations fail to halt. Possibly in the operations overseas of the Royal Air Force itself the best analogy of the position is to be found. In dealing with unruly tribes on the frontiers of the Empire and its protectorates, it has on occasion been proved very effective to address them from the air by means of ultra-loud speakers. If this method fails to bring the offenders to a right course of behavior, our machines are sent forth to drop dummy bombs on them. Actual bombing is the final resort, and it is on record that it is seldom required, the mere sight of our aircraft, or the certain knowledge that they are within easy reach, frequently being sufficient to stop trouble. It would, perhaps, be ungracious to compare other nations with the tribesmen of the Aden hinterland or the North-West Frontier, but it is to be sincerely hoped that they will recognize that in our aerial policy we have now reached the "loud-speaker" stage, and that if they fail to respond, the "dummy bomb" phase will follow. It ought to be unnecessary at this date for Great Britain to demonstrate to all concerned that she has the power and the ability to produce the machines, in number and quality, required to give her parity with any other nation. Our Air Force at present may be small in numbers,

but it is backed by a highly organized, self-contained manufacturing industry, capable of rapidly increasing its output, and supported by an extensive and very efficient body of research workers and investigators. We are to-day in the forefront of the nations as regards the production and development of aircraft and aerial material. If the appearance of our six new squadrons during the coming year serves in any way to emphasize that fact, the effort and expenditure involved will be repaid.

There are many critics of the Government who charge it with having no aerial policy at all, or with making completely ineffective provision to meet the dangerous situation into which it has in pursuit of its policy allowed the country to drift. It is certainly within our power to adopt a more heroic measure than that to which the Government is now committed, to provide not six but sixty new squadrons, and at one bound to place ourselves on a footing of equality with, and even superiority to, the strongest aerial Power of to-day. The expense would be great, but if such a policy carried with it any guarantee for the maintenance of peace it would be justified. It is, however, fairly certain that to proceed in this manner would defeat the end we have in view, the agreed limitation or abolition of military aircraft. The fear of aerial attack prevails throughout the nations, and the only remedy against it which commands approval outside our own country is to play upon the fears of possible enemies. To this deplorable position has thirty years' development of one of man's most brilliant achievements reduced humanity. Great Britain has to-day a part to play as great as any in her history. It is for her to lead the nations back to sanity, to assist them to cast out their fears and their mutual distrusts, and to remove the horror and menace to mankind which the continued development of military aviation on an unrestricted basis will assuredly entail. The occasion demands wise statesmanship, characterized by firmness and an absence of panic. The object to be attained is more than our own immediate security; it amounts in effect to the salvation of humanity from ultimate destruction by products of man's own making. The Government's air program will not alter our relative position among the world's aerial Powers, and will prolong the period of risk through which we are now passing. We cannot, however, condemn it on either score, for its moderation is founded on humane sentiments. The final object on which we have set our hopes is too great to allow considerations of prestige or of complete safety to dominate our outlook.—"The Engineer," March 16, 1934.

AIRCRAFT CARRIERS.*

By Sir Arthur W. Johns, K.C.B., C.B.E.

The leading navies have adopted the aircraft carrier as a necessary type of warship, and with the capital ship, the cruiser, and the destroyer, the newcomer has been limited by the Washington and London Treaties in unit displacement, in total displacement per navy, and in caliber of the main armament. The London Treaty defines an aircraft carrier as any surface vessel of war, whatever its displacement, designed for the specific and exclusive purpose of carrying aircraft, and so constructed that aircraft can be launched therefrom and landed thereon. The caliber of gun mounted must not exceed 8 inches, and by the Washington Treaty, the standard displacement must not exceed 27,000 tons. By the terms of the same Treaty the British Empire and the United States may each have a total tonnage of

* Paper read before the Institution of Naval Architects on Wednesday, March 21, 1934. Abridged.

carriers of 135,000, Japan 81,000, and France and Italy 60,000 each. Those vessels, which were fitted out during the war and arranged so that aircraft could be flown off but not landed on, are now termed "seaplane carriers." The *Albatross* of the Royal Australian Navy, and *Commandant Teste* of the French Navy are the latest examples of this type. Their tonnage is not included in that allowed by the Washington Treaty. By the Washington Treaty, all aircraft carrier tonnage in existence or building on November 12, 1921, is considered experimental, and can be replaced within the total tonnage limit without regard to age. The *Argus, Hermes, Eagle,* and *Furious* of the British Empire, *Langley* of the United States, and *Hosho* of Japan fall within this category. Carriers commenced after that date cannot be replaced until twenty years after their completion.

The germs of the design of the aircraft carrier—the flying-off deck forward, the landing-on deck aft, and the arresting gear on the latter, were embodied on the United States cruisers *Birmingham* and *Pennsylvania* in 1910 and 1911, and were used by Ely to fly and land an aeroplane. In December, 1911, Commander Samson repeated Ely's exploit by flying off a sloping trackway built over the fore barbette and deck of the battleship *Africa* while at anchor at the Nore. The aircraft used by him was a Short biplane fitted with wheels, to which buoyancy air-bags had been fitted. In 1912, Commander Samson flew off similar tracks fitted in the battleships *Hibernia* and *London* when steaming at 10½ to 12 knots. Landing-on was not attempted. These early experiences showed plainly that if aircraft were to be carried by the ordinary warship the platforms necessary for taking-off and landing-on would impose very serious restrictions on the main gun armament, and that seaplanes seemed the preferable type to employ, as they could take-off in a calm sea, and alight on the water when returning to the ship, or in the event of engine failure. The platforms might therefore be omitted, the seaplanes being stowed amidships and hoisted in and out by derricks.

In December, 1912, Messrs. Beardmore submitted to the Admiralty a design for a "Parent Ship for Naval Aeroplanes and Torpedo-Boat Destroyers" which had been worked out very fully. The displacement was 15,000 tons, length 430 feet, beam on water-line 82 feet, and speed 15 knots. The upper or flight deck—450 feet long and 110 feet wide—had side houses for a length of about 220 feet, through which the funnels, boiler and engine-room ventilators, etc., passed, and also housed six aeroplanes with wings spread, each in its own hangar. Four aeroplanes with wings detached were stowed in the forward hold and could be struck down or lifted out by either of the two forward cranes. Between the side houses was an open deck about 50 feet wide which could be closed in at the fore-end by hinged inclined gates. If the open forecastle deck proved to be of insufficient length for an aircraft to fly off, it could start in the passageway. Similarly, aircraft landing on the quarter-deck might finish their flight in the passageway. Although in a calm sea very experienced pilots might find the width of passage adequate, yet it was evident that in a seaway a 50-foot width was certainly on the small side, especially with a transverse form of ship whose rolling would be erratic and irregular. Six years later, Messrs. Beardmore completed the first aircraft carrier, the *Argus.* In the Navy Estimates for 1914-15, £81,000 was included for a new ship "for carrying seaplanes," but its construction was anticipated by the purchase at the end of 1913 of a merchant ship then under construction at the Blyth Shipbuilding Company's works, which later was named *Ark Royal.* She was completely redesigned, amongst the alterations being the transfer of the propelling machinery from amidships to aft; the provision of a long hold for the stowage of seaplanes; the cutting of a large hatch, 40 feet by 30 feet

in the weather and main decks over the seaplane hold, and the protection of this hold by cellular water-spaces at the sides; the fitting of a crane on the upper deck on either side to deal with seaplanes in the hold or alongside the ship; the cutting down of the sheer of the forward weather deck and the removal of the anchor and cable gear to the deck below to facilitate the flying-off of aircraft; and the provision of work-shop spaces for repair work. As redesigned, the *Ark Royal* could accommodate ten seaplanes, had a clear level flying-off deck 103 feet long, and numerous ballast tanks by the use of which the flying-off deck could be given a slight slope forward. Laid down on November 7, 1913, the work of conversion was started in March, 1914, she was launched in September, and left Blyth on January 10, 1915. She was 353 feet long, 51 feet beam, of 7450 tons displacement, with a speed of 11 knots. Her speed was too low for fleet work but she is still in commission for experimental aircraft work.

At the outbreak of war, the British Navy had no aircraft carriers, but *Hermes* was soon afterwards refitted with the trackway over the fore-deck and proceeded on service at Dover, but was sunk by an enemy submarine in October, 1914. Three cross-channel steamers, *Empress, Engadine,* and *Riviera,* were rapidly fitted out as seaplane carriers with improvized hangars at the stern and derricks for lifting the aircraft into and out of the water. Later *Vindex* (1915) and *Manxman* (1916) were taken over and converted with hangar and cranes for seaplanes aft and a hangar and flying-off platform for aeroplanes forward. Experience was showing that for services in the North Sea aeroplanes were preferable to seaplanes, the only advantage of the latter being their ability to alight on the water. The aeroplanes were fitted with airbags on their undercarriage to keep them afloat. The *Campania* was purchased and fitted with a forward hangar to take ten seaplanes and a forward flying-off deck, 230 feet long, from which seaplanes were launched with wheeled trucks under the floats. These trucks were detachable by the aviator when he had left the deck, but were later automatically freed by fittings on the deck. By the end of 1916 experience had shown that aeroplanes were superior to seaplanes, and that larger and faster carriers than those available were necessary for service in the North Sea in conjunction with the fast cruisers. With the larger and faster ships, landing-on of aircraft might be facilitated, this being an urgent necessity now that aeroplanes were to be more generally employed. In March, 1917, it was decided to convert the light cruiser *Furious* for this service. The forward barbette and guns were removed, and a flying-off platform, 228 feet long and 50 feet wide, with a hangar immediately below, was fitted over the forecastle. It was hoped that landing-on would be feasible on such a large area, especially at the speed which the ship could attain. But while flying-off proved relatively easy, landing-on led to a fatal accident and was forbidden. In the autumn of 1917 it was decided to remove the after-turret and mainmast and fit a landing-on deck 284 feet long and 70 feet wide, extending from the funnel to the after-end, with a hangar below. Aircraft successfully landed on this deck, although the disturbed air behind the funnel made the operation difficult. *Furious* was thus the first British warship to be converted into a complete aircraft carrier with flying-off and landing-on decks.

These experiences with *Furious* were of great advantage in converting the *Argus* to an aircraft carrier. A flight deck was built extending nearly the whole length of the ship, and immediately under this, near the middle line, two horizontal funnel ducts were fitted, the smoke and gases being expelled at the sides aft by large suction fans. Below the ducts, a hangar 330 feet long, with a large lift for transport of aircraft from hangar to flight deck and vice versa, was installed, together with workshops and stores. Originally, small deck-houses on either side of the flight deck, with a navigating bridge

spanning them, were a feature of the design, but after the difficulties in landing-on on the *Furious* deck, these deck erections in *Argus* were omitted, and a disappearing chart-house and navigating position fitted forward. The *Argus* was completed on September 16, 1918, the embodiment of all those ideas and experiences which had been so painfully acquired by the naval air arm during four years of war, and although too late to take an effective part in it, she was put to good use in trying out various proposals which were under consideration to improve landing conditions in aircraft carriers, which were then in course of construction or conversion. One of these was an arresting device whose purpose was to decelerate more rapidly the aircraft after it had landed on the deck.* A number of wires were stretched longitudinally over the flight deck, 9 inches apart and 15 inches above the deck, kept in position by light hinged hurdles which were knocked down by the wheels of the machine when passing them. When landed on the deck, hooks on the axle of the aircraft engaged a number of the wires and brought it to rest, at the same time preventing it moving too far towards the deck edge—a tendency which was very marked in an aircraft slowing down, when the rudder control became less effective. A satisfactory solution was obtained, and this gear was fitted and used in carriers until 1925, when it was removed and inclined palisades added at the deck edges to prevent aeroplanes which had made a bad landing going over the side. Mechanically-worked palisades at the deck edges for the latter purpose were also tried out on the *Argus*. Another interesting experiment was that of "mocking-up" a streamlined "island" on the starboard side, representing a vertical funnel with navigating bridge, etc., at its forward extremity, to ascertain its effect on the air currents over the flight deck.

The order for the *Hermes*—the only British carrier originally designed as such—was placed with Messrs. Armstrong in July, 1917, and towards the end of the same year the Chilean battleship *Almirante Cochrane*, then almost ready for launching at Messrs. Armstrong's, was purchased for conversion to a carrier and renamed *Eagle*. Both these vessels were completed at the dockyards in February, 1924, and both have full-length flight decks with an "island" on the starboard side, through which pass the funnel uptakes and mast, and from which navigation is effected. In both ships, the after-end of the flight deck is carried to the after-end of the ship and gently curved downwards to obviate eddying and danger of the undercarriage of an aircraft bringing up against the transverse edge of the deck. There still remained some little doubt as to the effect of the "island," and the *Furious*, on her next conversion, was arranged as a flush-deck vessel with horizontal funnel ducts on either side under the flight deck and outside the hangar. She was the first British aircraft carrier to be fitted with two-storied hangars and with the flight deck not carried to the fore-end. The deck forming the floor of the upper hangar was carried to the fore-end of the ship and a slight downward slope given to it, forming a subsidiary flying-off deck. *Courageous* and *Glorious* were the last to be converted, and in these the "island" was reverted to, being made as short and placed as far forward as practicable. The flight deck is cut short as in *Furious*.

It is of interest to compare the characteristics of British aircraft carriers with those of other navies, as given in the annexed table. Of fifteen completed, only four were designed originally as carriers, viz., *Hermes, Hosho, Ranger*, and *Ryujo*. Of those converted to carriers, *Béarn, Eagle*, and *Kaga* were battleships; *Akagi, Lexington* and *Saratoga* battle cruisers; *Courageous, Furious* and *Glorious* lightly-armored battle-cruisers; *Argus* a mail and passenger ship; and *Langley* was the naval collier *Jupiter*, which Con-

* See "Deck Flying," by Squadron-Leader Acland, Journal of Royal Aeronautical Society, May, 1931.

gress ordered to be converted in 1921. In ten carriers—three British, four U. S. A., two Japanese, and the French—there is one flight deck which extends over the whole length of ship or nearly so, whilst in the other five the flight deck is stopped at an appreciable distance from the bow, thus allowing for a short flying-off deck below the main one. Different methods of aircraft operation account for these two arrangements of the decks. Eight of the carriers are of the "island" type, with the funnels, mast, navigating positions, etc., on the starboard side of the flight deck; the remaining seven have the flush or clear type of flight deck. The United States *Ranger*, designed with a flush flight deck, has been altered to the "island" type during construction. In the flush-deck carrier the disposal of the boiler smoke and gases, so that they shall not inconvenience pilots about to land-on, is a problem. *Argus* and *Furious* have horizontal ducts on either side immediately under the flight deck and extending almost to the stern, where they are bent downwards, the contents being forcibly directed to the sea, where they are in great part condensed or deposited. *Kaga* has similar ducts, but with the outlets higher. *Hosho's* three funnels, which project above the flight deck when upright, are hinged, and are turned outboard and horizontal when flying operations are in progress. The two much smaller funnels of *Langley* are stated to be fitted similarly. *Akagi* has a single funnel on starboard side horizontal and transverse with the outer end turned down, whilst *Ryujo's* two funnels are transverse and horizontal.

PARTICULARS OF BRITISH AND FOREIGN AIRCRAFT CARRIERS.

Ship.	Date of Completion.	Length, ft.	Beam, ft.	Displacement, tons.	Speed, knots.	S.H.P.	Armament.	Approximate Number of Aircraft.
BRITISH:—								
Argus	1918	567	75	14,450	20	20,000	6 4-in. A.A.	15
Hermes	1924	600	70	10,850	25	40,000	6 5·5-in. 3 4-in. A.A.	15
Eagle	1924	667	105	22,600	24	50,000	9 6-in. 4 4-in. A.A.	21
Furious	1925	786	90	22,450	31	90,000	10 5·5-in. 3 4-in. A.A.	35
Courageous	1928	786	90	22,500	30¼	90,000	16 4·7-in. A.A.	50
Glorious	1930	786	90	22,500	30¼	90,000	16 4·7-in. A.A.	50
UNITED STATES:—								
Langley	1922	542	65	11,500	15	7,150	4 5-in.	30
Saratoga	1927	888	106	33,000	34	180,000	8 8-in. 12 5-in. A.A.	80
Lexington	1927	888	106	33,000	34	180,000	8 8-in. 12 5-in. A.A.	80
Ranger	1934	765	80	13,800	29½	53,500	8 5-in. A.A.	76
Yorktown	—	—	—	20,000	—	—	—	—
Enterprise	—	—	—	20,000	—	—	—	—
No. 1	—	—	—	15,000	—	—	—	—
JAPAN:—								
Hosho	1922	510	48	7,470	25	30,000	4 5·5-in. 2 3-in. A.A.	26
Akagi	1927	763	92	26,900	28½	131,200	10 8-in. 12 4·7-in. A.A.	50
Kaga	1928	715	102	26,900	23	91,000	10 8-in. 12 4·7-in. A.A.	60
Ryujo	1933	540	61	7,100	25	40,000	12 5·1-in. A.A.	—
No. 1	—	—	—	10,000	—	—	—	—
No. 2	—	—	—	10,000	—	—	—	—
FRANCE:—								
Béarn	1928	597	80	22,146	21½	37,000	8 6·1-in. 6 3-in. A.A.	40

The trend of design is to the "island" type of carrier, experience having shown that if the obstacle is short, relatively narrow and streamlined, there is little or no interference with the air currents over the after-portion of the flight deck. In a small carrier such as *Ryujo*, where the length is shorter and the breadth of flight deck is appreciably less than in the larger vessels, the relatively larger breadth of "island" may cause more serious interference. The "island" arrangement is generally lighter and allows of a wider

and cooler hangar and an increased stowage for aircraft. It has the disadvantage of making the ship arrangements in the vicinity unsymmetrical, tending to make navigation at times a little difficult, and introducing a heeling moment which is of some concern to the ship's officers in maintaining the ship upright. In the *Glorious* and *Courageous* this lack of symmetry is represented by 14,000 foot-tons, but in the *Lexington* and *Saratoga*, where the four twin 8-inch guns are in the same fore-and-aft line as the "island," this moment must be far greater and more troublesome. The displacements range between the 7100 tons of *Ryujo* and the 33,000 tons of *Lexington* and *Saratoga*, both limits being consequent on the decisions arrived at by the Washington Conference. The U. S. A., with an agreed total of 135,000 tons, had on completion of *Lexington* and *Saratoga* 69,000 tons to spare, and decided to build five carriers of 13,800 tons each, of which *Ranger* was the first. The *Yorktown* and *Enterprise*, ordered last August, are of 20,000 tons each, and presumably the naval authorities consider carriers of this tonnage are superior to those of 13,800 tons. Japan, on completion of the *Kaga* and *Akagi*, had 27,200 available tonnage, and are using this in the *Ryujo* of 7100 tons and two others of 10,000 tons each. Omitting the oldest carriers, the speeds in the table vary between 23 knots and 34 knots, but here again the converted ships have the power and speed given them for their designed purpose. Speed is determined by tactical considerations, but as for aircraft operations the carrier may have to steam into the wind, she will at times be on a different course from that of the Fleet of which she forms a unit. In order to keep station she must be generally of a greater speed than the other units. Frequent alterations of speed are therefore necessary and the propelling machinery must be robust and flexible. The effect of an increase of speed of a carrier on the number of aircraft appears in the evidence given to the Navy Committee of the Congress in 1929, when it was stated that an additional 3 knots to *Ranger's* speed would reduce the aircraft capacity by 40 per cent. But whilst comparisons of numbers of aircraft in carriers of the same navy can be fairly made, those with carriers of different navies are on a very different basis. Thus *Courageous*, of 22,500 tons, is credited with 50, and *Ranger*, of 13,800 tons, with 76. One knot difference in speed accounts for some of this difference, but it is also known there is a greater percentage of small aircraft in American carriers than in British, and, in addition, a number in the former are stowed on the flight deck, a stowage not adopted in British carriers.

There are many arrangements in aircraft carriers not in ordinary warships. The hangars, 17 feet or 18 feet in height, 50 feet to 60 feet wide, and 400 feet to 500 feet long, are huge open spaces not found in any other type of ship. They generally contain petrol gas to a greater or less degree, and are treated as dangerous spaces. Fixed divisional transverse bulkheads being inadmissible, subdivision of the hangars is secured by steel roller fire curtains operated by electric motors at the top, with further subdivision by heavy curtains of fireproof material. For the suppression of fire, a water system connected to the ship's fire main and also to special fire pumps and on the sprinkler principle, is fitted throughout the hangars, and can be operated almost instantaneously from stations in every section of the hangars, whilst fires on the flight deck are dealt with by continuous foam generators. Special exhaust ventilation is fitted to the hangars for the removal of dangerous gases, and is effected by electric fans outside the hangars and acting on the injector principle through trunks reaching nearly to the floors of the hangars. Electric leads are kept clear of the hangar spaces, but when these are necessary and must be fitted near the floor, very low voltage is used. Air-locks are fitted to all access doors to the hangars between decks. The large lifts to transport aircraft from the hangars to the flight deck or vice versa are a

special feature. Two are generally fitted, one at either end of the hangar space, and as the aircraft may have their wings spread the lift platforms are nearly 50 feet wide and 45 feet long. In the latest carriers these lifts are hydraulically operated and are of relatively high speed. Compensation for loss of strength of the deck in the vicinity of the lift demands attention. As the hangars occupy 50 feet or 60 feet of the middle of the breadth of the ship over a considerable portion of the length and must be clear of obstacles, the funnel uptakes, engine- and boiler-room ventilating shafts, ship ventilating trunks, and all ladderways have to be brought to the sides of the ship before the level of the floor of the hangars is reached. The spaces at the sides of the ship outside the hangars are thus congested. The stowage of boats is far more difficult than in the ordinary warship, neither davits nor derricks being practicable. Horizontal transverse girders and runways take their place. The ready supply of ammunition to the guns is also rendered difficult. The stowage of aviation spirit in the requisite quantity for the operation of a large number of aircraft is a problem peculiar to the aircraft carrier. This is carried in a number of large cylinders at either end of the ship, fitted in the hold and independent of the ship's structure. An extensive system of piping is fitted, with fuelling positions in every section of the hangars and on the flight deck. This petrol system is operated either by air pressure or in some carriers by a water-displacement system. Gravity ready-use tanks are fitted on either side of the ship under the flight deck, and arranged for quick disconnection and rolling overboard and sinking in the event of any danger.

Arresting gear presents another interesting and troublesome problem. The gear has to be designed to decelerate the several types of aircraft whose weight may vary from 3000 pounds to 8000 pounds, and whose relative speeds when engaging a wire of the gear may vary over a large range, without bringing on the aircraft a deceleration greater than that for which it is designed. Admiral Rock,* Chief Constructor of the United States Navy, has stated:—"Of all the aviation facilities on an aircraft carrier, which have required special development, the arresting gear has undoubtedly demanded the most experimental and pioneer effort." Our own experience, although far less extensive, full confirms Admiral Rock's statement. Large transverse wind screens on the forward end of the flying-off deck are another feature in carriers. These, when raised to the vertical position, provide a shelter behind which aircraft can make the final adjustments previous to taking-off. These screens are so shaped and housed on the deck that when down they offer no obstacle to the smooth passage of aircraft over them. Longitudinal screens for the same purpose are fitted in some carriers at the deck edge, especially in the flush-deck type of carrier. In the other type, the "island" itself is of great advantage for this purpose.—"Engineering," March 30, 1934.

PRESENT DAY CRUISERS.

Is the Admiralty Making the Best of the Washington Conference?

The interest of shipbuilders in this country is centered round the new 9000-ton cruisers for the Government. With the limitation of displacement imposed by the Washington Conference, naval constructors, the world over, have been devising means for securing the best fighting capacity within these limits. The desirable features required are good offensive and defensive qualities with the best speed possible; the designs produced naturally show the in-

* See Proceedings of the Society of Naval Architects and Marine Engineers, 1928.

fluence of the particular advocacy of strength of armament, or of good defense, or of high speed. It is possible that the British designs show a balanced arrangement unexcelled in contemporary cruiser design.

While the limit of 10,000 tons has been set as the standard displacement of this class of ship the vessels which have been built in this country in recent years have belonged to either the *Arethusa* type of 5200 tons or the *Leander* type of 7000 tons. From the standpoint of affording fighting strength the building of vessels of these relatively small tonnages cannot be justified. It was stated in the House that the policy of building cruisers of comparatively small tonnage had been adopted in the hope that other nations would follow our lead. Also British delegates at Geneva put forward proposals for the reduction of future cruisers to 7000 tons with a maximum gun caliber of 6.1 inches, in the hope that these would be generally accepted. Unfortunately neither of these hopes had been realized. In 1931 Japan laid down two cruisers of 8500 tons, mounting fifteen 6.1-inch guns, while the U. S. have announced the intention of building four 10,000-ton cruisers, each with fifteen 6.1-inch guns.

In view of this attitude of other maritime powers the construction of the 9000-ton cruisers was decided upon.

Apart from the desire to give a lead to other powers in the building of relatively small ships, financial considerations doubtless were a determining factor in the type of ship to be built. The estimated cost of an *Arethusa* type of 5200 tons is £1,250,000: of a *Leander* type of 7000 tons about £1,600,000, while a 10,000-ton vessel will be about £2,250,000.

The desirable qualities in cruiser design are good armament, good protection and high speed; with the limitation to the displacements of the *Arethusa* and *Leander* types some desirable feature must be sacrificed. It has been found possible to maintain the same speeds in each of these types, but the smallest type mount only six 6-inch guns, the *Leander* type eight 6-inch guns, and our 10,000-ton cruisers of the *London* class eight 8-inch guns. Naturally, also, the protection afforded to the vital parts of the ships is not so good in the lighter as in the heavier class vessels.

Concentration in the designing of this type has brought about a remarkable advance since the corresponding vessels were built in 1914. The following figures for the *Birmingham*, completed just before the war, and the *Leander* in 1933 are interesting in this connection:—

	Birmingham	*Leander*
Length between perpendiculars, feet	430	522
Length overall, feet	457	554
Breadth, feet	50	55
Mean draught, feet	16	16
Displacement, tons	5440	7140
Horsepower	25,000	72,000
Maximum speed, knots	25½	32½
Main armament, inch guns	9–6	8–6
Torpedo tubes, inches	2–21	8–21
Cost (including guns), pounds	353,437	1,667,819

The two features which are prominent in the above comparison are the remarkable advance in power and speed and the tremendous difference in the cost. With regard to the former it is apparent from the constancy of the speeds in the types of cruisers being built in this country that this is considered to be the most desirable feature. Probably this has been aimed at so that all the classes can keep together at high speed in the event of an engagement. In the German 10,000-ton cruisers a remarkably powerful group of guns

has been provided, viz., six 11-inch, eight 5.9 inch, and four 3.4-inch, but the speed has been reduced to 26 knots as compared with the 32½ knots in contemporary British vessels. Doubtless our tactical experts can justify their choice for speed rather than for gun-power.

The other striking feature, that relating to cost, is illustrative of the increase in construction and equipment values. Doubtless a considerable proportion of the increase can be attributed to the much higher power installed and to the amount of protection afforded, although no indication of the latter is given in the above comparison.

In due course there will be available information regarding the 9000-ton design, but the opinion may be expressed that full advantage might have been taken of the 10,000-ton limit so that the most powerful units possible under the agreement would have been added to the naval forces of the country.—"Shipbuilding and Shipping Record," April, 19, 1934.

THE NEW HYDROGEN.

Lecturing on the above subject at the Royal Institution on Friday, March 23, Lord Rutherford said that for more than a century scientific men had believed that water was a definite chemical substance, H_2O, which had definite and reproducible properties. So certain were they that it was a definite substance that when a unit of weight was required it was given in terms of 1000 cubic centimeters of water. Later, however, the standard was expressed in terms of a mass of metal. Less than four years ago water was regarded with confidence as a definite substance.

The first gentle shock this belief received resulted from the discovery of the complexity of oxygen. It was first supposed that oxygen was a simple element with an atomic weight of 16, but as a result of investigations it was found that isotopes were always present in oxygen gas, a few having an atomic weight of 17 and still more a weight of 18. This shock was small, but last year a discovery was made which was destined to have a revolutionary effect on our ideas. This was that hydrogen was also a complex substance. The ordinary hydrogen molecule was taken as having a mass 1 in terms of oxygen of weight 16, but there was also found to be present in the former an isotope of mass 2. The amount of the latter present was of the order of one part in 6000 of the ordinary hydrogen. The difference in the case of the oxygen isotope was from 16 to 18, but the hydrogen isotope was double the mass of the ordinary hydrogen atom. That difference of mass made it possible to alter the relative concentration of the two isotopes of hydrogen in water, so much so that it was possible to prepare a water in which each hydrogen atom was replaced by one of twice the mass. We could, in fact, produce pure water in which the weight of hydrogen was twice that of ordinary water.

This water was the same as ordinary water in appearance, but it had very different properties. Lord Rutherford showed some of this heavy water which had been produced in the Cavendish Laboratory; in one bottle the proportion of heavy hydrogen was 30 per cent, and in another 91.5 per cent. The density of pure heavy water was some 10 per cent greater than that of ordinary water, so that a person could float in it easily. Of its other properties, Lord Rutherford said its freezing point was 1.4 degrees C. and its boiling point 3.8 degrees C. higher than that of ordinary water. The other properties, such as vapor pressure, latent heat, surface tension, viscosity, etc., all differed from those of ordinary water.

The lecturer then proceeded to consider how the discovery of the new hydrogen had been made, remarking that it was largely the work of his col-

leagues in the United States. The study of the separation of heavy water was, he said, a romantic story, resembling in some respects the discovery of argon by the late Lord Rayleigh. The first indication of another hydrogen was the result of careful comparisons and belief in the value of accurate measurements. Long ago the relative weight of oxygen to hydrogen had been determined by a combination of chemical and physical methods, that of oxygen being taken as 16 and hydrogen as 1.0078 nearly. In recent years, Dr. Aston's method of comparing the masses of isotopes by means of flying charged atoms gave results in good agreement with the chemist. Oxygen was then believed to be a simple element of atomic mass 16, but later it was found to contain a number of atoms of mass 18. Allowing for this, it was found that two measurements which should have been in agreement were 1 part in 5000 in error. This discrepancy was rather beyond the possible error of the measurements, and it was suggested that the difficulty could be got over if there existed in hydrogen an isotope of mass 2. It was estimated that there should be one such heavy atom with 4000 ordinary atoms.

This suggestion required a good deal of faith, but it was thought worthy of experimental investigation. Professors Urey, Brickwedde, and Murphy tried to see if they could detect the hydrogen isotope, but the question arose as to how it should be recognized, and this, Lord Rutherford explained, had been done by an examination of the hydrogen spectrum. It could be shown that if the heavy isotope of hydrogen were present a weak satellite should be found near each of the main hydrogen lines and at a distance of 1.78 Ångstrom units from the Hα line. Experiments were made to see if the satellites could be made stronger by fractional distillation of liquid hydrogen, and with some success. An observation made by Urey and Washbourn had a considerable effect on the development. They found that in an ordinary lead accumulator which had been used for some years the concentration of heavy water in the acid of the cell was five times that obtained in ordinary water. This meant that when water was electrolyzed the ordinary hydrogen escaped five times as rapidly as the heavy hydrogen relatively to the concentration. Acting on this idea, Professor Lewis, in the University of California, proceeded to electrolyze water to enrich the amount of the heavy isotope. He was soon successful in obtaining a few cubic centimeters of pure heavy water in which the ordinary hydrogen was entirely replaced by heavy hydrogen. Lord Rutherford exhibited about 30 cubic centimeters of pure heavy water produced at Cambridge. It was obtained, he said, by electrolyzing several gallons of ordinary water, in which the concentration of the heavy hydrogen was one part in 6000, to about one-twentieth of its volume, in which the concentration of the heavy hydrogen would be about 10 times that at the commencement of the process. This water was electrolyzed again and so on, until pure heavy water was finally obtained. The production of this heavy water was thus an expensive process unless electric power was very cheap.

Lord Rutherford then showed a number of simple experiments to illustrate the properties of heavy water, including one which showed that the heat conductivity of heavy hydrogen was less than that of ordinary hydrogen. For this purpose he used two glass bulbs each having a platinum wire passing through it, one of the bulbs being filled with heavy hydrogen and the other with ordinary hydrogen. Both wires were of the same length and diameter, but when a current was passed through the two in series, that in the bulb containing the heavy hydrogen became hotter than that in the ordinary hydrogen because the conductivity of the latter was the higher of the two, and thus allowed the heat to escape more rapidly.

Continuing, Lord Rutherford said heavy hydrogen and ordinary hydrogen could be separated by a diffusion process due to Professor Hertz. By this method heavy hydrogen had been obtained so pure that ordinary hydrogen

could not be detected in it. Slides illustrating the spectra of ordinary and heavy hydrogen were shown and appeared to be very similar, but Lord Rutherford remarked that the slight differences would undoubtedly be carefully gone into. No difference, he added, could be seen between the electric discharge in hydrogen or heavy-hydrogen tubes.

In Lord Rutherford's opinion, the discovery of heavy hydrogen would lead to important scientific developments. When it was remembered, he said, what an enormous part hydrogen played as a compound in chemistry, it would be seen that the discovery was of immense interest to chemists. It was possible to replace the ordinary hydrogen by heavy hydrogen in any compound, and marked changes might ensue. Much work would have to be done to investigate these new varieties of compounds. What, the lecturer asked, would be the effect of the discovery on biological processes?

It had been found that tobacco seed would not germinate in heavy water, but there had not yet been time for definite discoveries. A very interesting field of work was opened for investigating the effects of heavy hydrogen on animal and plant life.

Continuing, Lord Rutherford said it seemed desirable that there should be a name for the new isotope of mass 2, since it was bound to play an important part in the future. Professor Urey had suggested that the new isotope should be called deuterium and its nucleus deuton or deuteron, while the main isotope should be called proteum and its nucleus the proton, as at present. Lord Rutherford, however, preferred the new isotope to be called diplogen and its nucleus diplon, and thought the present names for ordinary hydrogen and its nucleus should be retained.

Turning to the question of the structure of the new isotope, the lecturer said its mass was not quite twice that of ordinary hydrogen, the figure for the former being 2.0136 and that for the latter 1.0078. It was natural to suppose that the diplon was made up of a proton and a neutron in combination, and if heavy hydrogen were bombarded with α-particles it should be possible to break it up into the two parts. Efforts had been made to do this at Cambridge and elsewhere, but without success. The difficulty of settling its structure would be obvious when it was remembered that the nucleus might be composed of negative or positive electrons, neutrons and protons mixed up in various ways.

Passing on to another point, Lord Rutherford said it was a very interesting coincidence that when Professor Lewis first produced heavy water, his colleague Professor Lawrence had developed an ingenious apparatus for accelerating protons to an energy of 1,000,000 or 2,000,000 volts. Using the heavy hydrogen in this apparatus he found very marked transformation effects, different from those obtained with light hydrogen; the transformations were more frequent and of a different type. The lecturer then showed an experiment to illustrate the transformation of lithium first by protons and then the effects of changing ordinary hydrogen by heavy hydrogen. The apparatus used was that employed in Lord Rutherford's concluding lecture on "The Transmutation of Matter." The experiments included the disintegration of lithium with protons and with diplons and also the bombardment of heavy hydrogen with its own diplons. These experiments were similar to those in the lecture above referred to, and particulars of them will be found in that article.

In conclusion, Lord Rutherford said the new hydrogen was extremely interesting, not only from the theoretical standpoint, but also to practical physicists in connection with the problem of the transmutation of matter. The results differed from those obtained with α-particles and protons, and it was hoped to gain important information from them.—"Engineering," April 20, 1934.

ASSOCIATION NOTES.

BANQUET.

The annual banquet of the Society, held in Washington on February 23, 1934, was one of the most successful ever held. The attendance was the largest of any of these events. Admiral William H. Standley, Chief of Naval Operations, our President, presided. Rear Admiral William D. Leahy, Chief of Bureau of Navigation, was toastmaster. Admiral Standley, Rear Admiral S. M. Robinson, Engineer-in-Chief of the Navy, and Dr. Frank Baldwin Jewett, Vice-President of A. T. & T. Co., and President of Bell Telephone Laboratories, made addresses. Mr. Strickland Gillilan contributed an excellent entertainment feature.

MEMBERSHIP.

The following have joined the Society since the publication of the February, 1934, JOURNAL:

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